Applications in Flood Risk Assessment - Rainfall-runoff estimation and forecasting using novel technologies

E.A. BALTAS, Professor

School of Civil Engineering
Division of Water Resources and Environment

NATIONAL TECHNICAL UNIVERSITY OF ATHENS

ATHENS 26 FEBRUARY, 2021

Structure

Elements of flood hydrology
Climate & Land use change impacts

- **Elements of flood hydrology**
  - Hydrographic network
  - Physiographic and geomorphological characteristics
  - Rainfall – Runoff models – Estimation of flood hydrographs
  - Real-time forecasting and warning
  - Hydrologic design and sizing of flood protection works
- **Climate change impacts on floods & flood risk**
- **Land use change impacts on floods & flood risk**

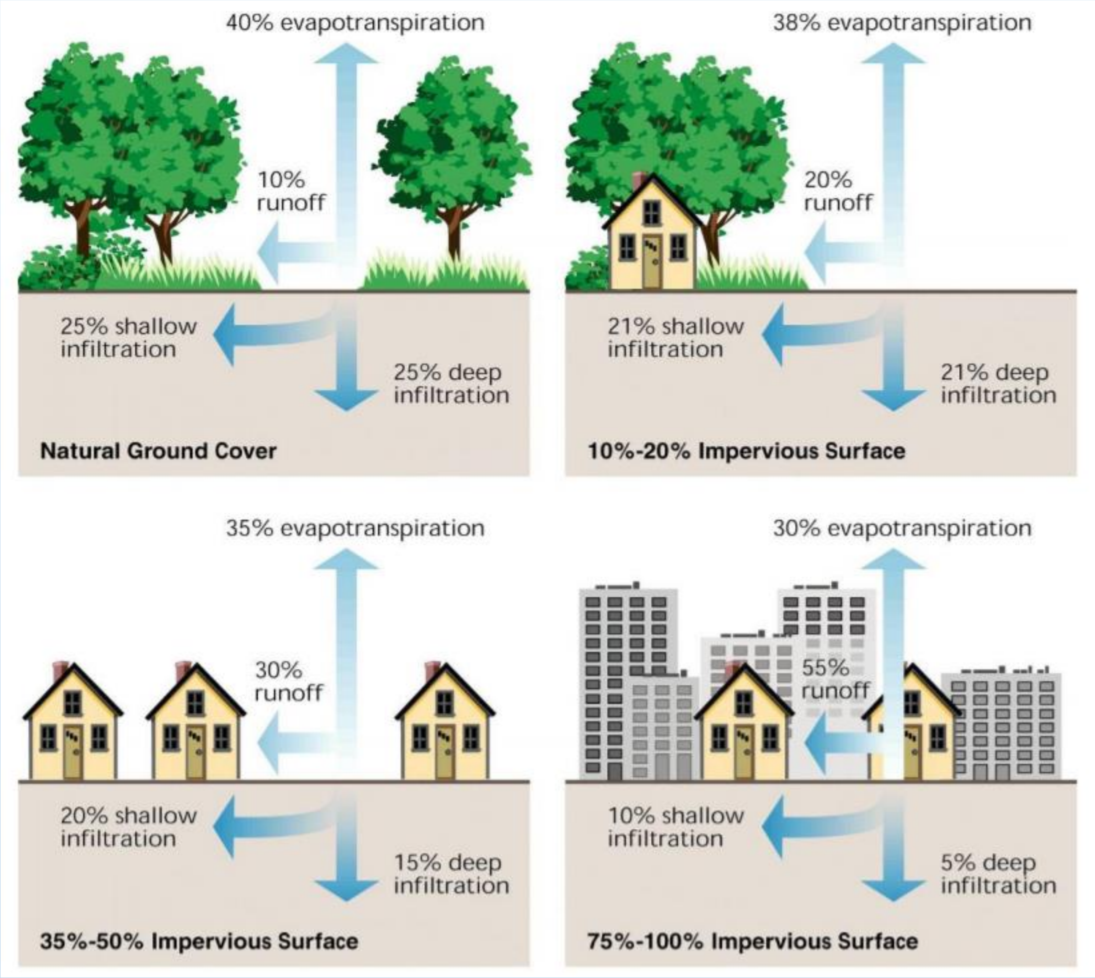
Causes of flood disasters (natural, anthropogenic)

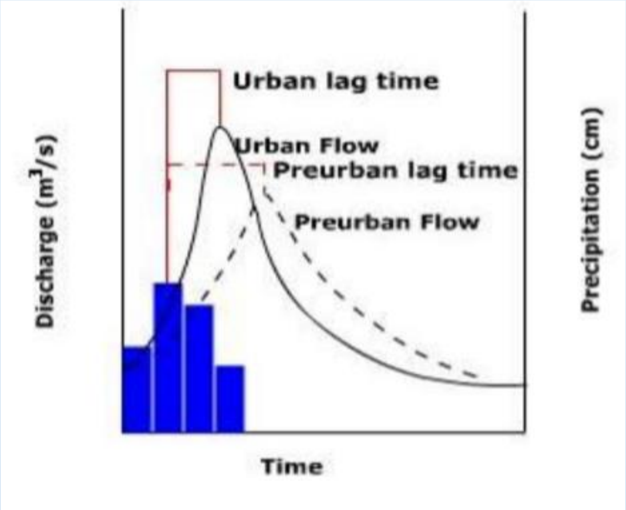
Anthropogenic factors leading to deterioration of flood risk

Storms are the natural cause of floods, however anthropogenic factors lead to the deterioration of flood risk. Particularly in urban regions, even small rainfall events can lead to catastrophic floods due to anthropogenic factors such as:

- Increasing urbanization and reduction in vegetation and forest areas ⇒ increase of the runoff coefficient (may increase from 25%-30% to 90%-95%)
- Disappearance of the hydrographic network of cities (urbanization)
- Insufficient stream conveyance capacity to adequately relief small flooding events
- Insufficiency of storm water drainage networks
- Obsolete flood protection works studies based on generic and/or wrong concepts
- Lack of systematic monitoring of runoff volumes and discharges ⇒ ineffective model calibration

Urban floods: Impact to the parameters of hydrological cycle





Πηγή: Urban Flood Risk Management (WMO, 2008)

Floods & Flood protection - Situation in Greece

- Significant geographical variability of climatic variables related to floods due to extensive coastline and orography
- Significant effect of Pindos mountain range on rainfall and runoff processes
- Significant variation of average annual rainfall from 1800mm (Western Greece) to 400mm (Eastern Greece) and water scarcity issues at the eastern regions
- Variation of maximum rainfall: Maximum 24-h rainfall for T=50y 175mm in Western Greece, 100mm eastern of Pindos mountain range and 175mm at the eastern Aegean islands
- Aggravated by geomorphological and vegetation characteristics, more catastrophic floods occur at the “dry” Eastern regions of Greece compared to the “wetter” Western regions

Flood protection studies and works

A comprehensive flood protection study includes:

- Identification of streams and surveying of the greater study area - Import into GIS system
- Mapping of the existing storm water drainage networks (if any)
- Development of IDF curves
- Hydrological study for main streams (drainage basins, peak discharges and flood volumes under different return periods)
- Assessment of risk zones (delineation of inundation areas under equal risk)
- Hydraulic study – Conveyance capacity assessment of existing stream cross sections –Identification of critical locations
- Assessment of the hydraulic sufficiency of existing works and identification of required modifications
- Proposals for constructive and non-constructive flood protection measures
- Program for the prioritization of flood protection works and measures

Non–structural flood protection measures

Non-structural flood protection measures pertain mainly to forecasting of severe storms and floods, providing early warning and planning of emergency response systems.

Implementation steps include:

- Installation of automated telemetry network of rainfall-runoff monitoring stations at critical locations
- Development of data collection and processing software
- Calibration of rainfall-runoff models
- Identification of critical locations
- Real-time storm & flood forecasting and monitoring systems (radar, satellite and ground-based stations)
- Early-warning systems for floods and composition of emergency plans
- Operational organization of regional authorities and stakeholders for prevention and reaction against flood disasters.

Hydrologic forecasting – Operational use

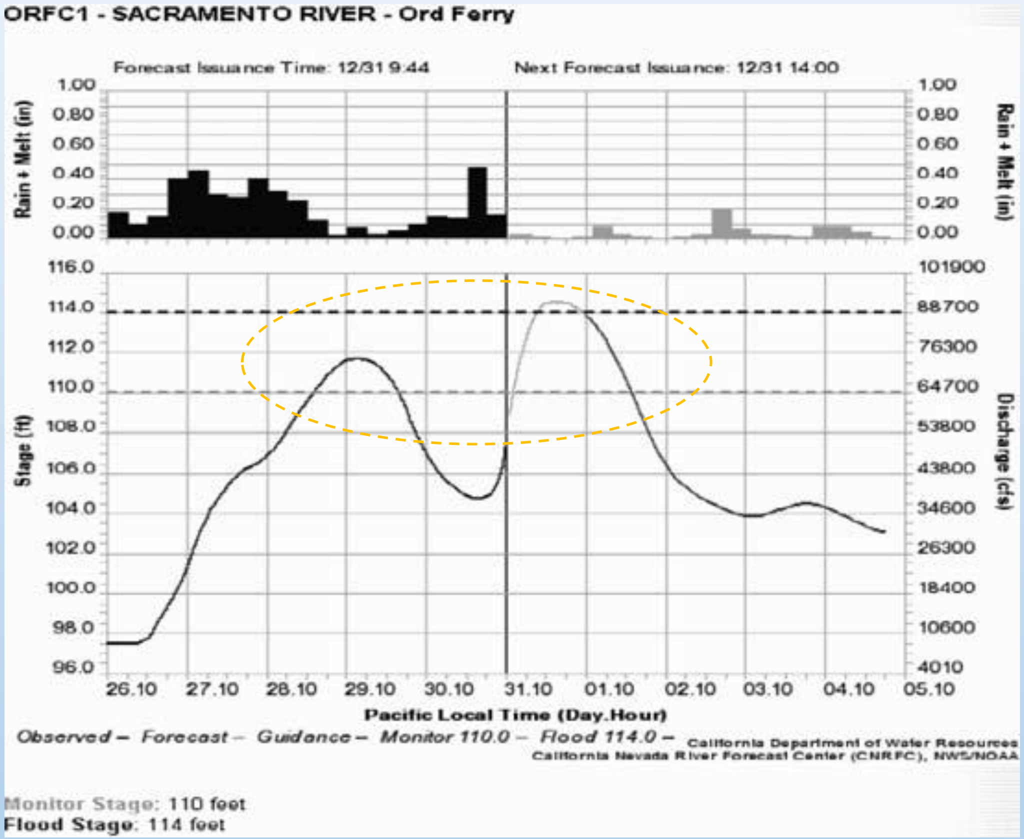
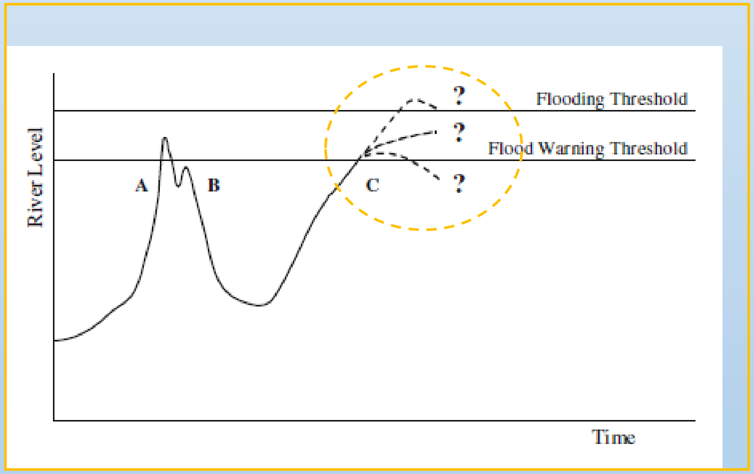


Illustration of river stage forecast guidance for Ord Ferry on the Sacramento River (California-Nevada River Forecast Center, http://www.cnrfc.noaa.gov/)



Basic principles

An early warning system refers to:

- a set of information regarding the potential emergency event
- transmitting a message to those concerned and
- supporting the decision making and rapid response of the authorities

An early warning systems requires integrated and coordinated collaboration between scientists, technical personnel, public authorities, stakeholders and the public.

Basic principles

General remarks on flood hazard

- the general public does not comprehend flood hazard
- the role of public authorities during flood event emergencies is not clearly defined
- the public needs to be informed on how to act before, during and after a flood
- educational campaigns to inform the public about floods
- the public demands that flood impacts are immediately addressed

- To make flood forecasting and early flood warning part of the national agenda instead of an issue that is only recognized during crises

- To encourage actively engaged stakeholders such as insurance companies, universities and institutes promote the issue to a national level

European Floods Directive (FD)

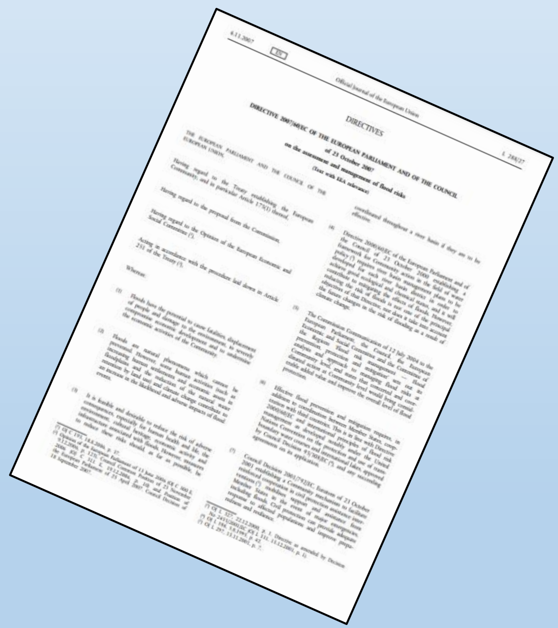
Entry into force: 26 November 2007

Target of the Directive

- To establish framework for the assessment and the management of flood risks, targeting at the prevention and mitigation of the adverse effects on human health, the environment, the cultural heritage and economic activities that are connected with floods. It can be considered as a complementary directive to the Water Framework Directibe.

Scope

The Floods Directive covers river floods, flash floods, urban floods, sewer floods and coastal floods.


Official Journal of the European Union
DIRECTIVES
DIRECTIVE 2007/60/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL
of 23 October 2007
on the assessment and management of flood risks
(Text with EEA relevance)

Axis for flood risk management

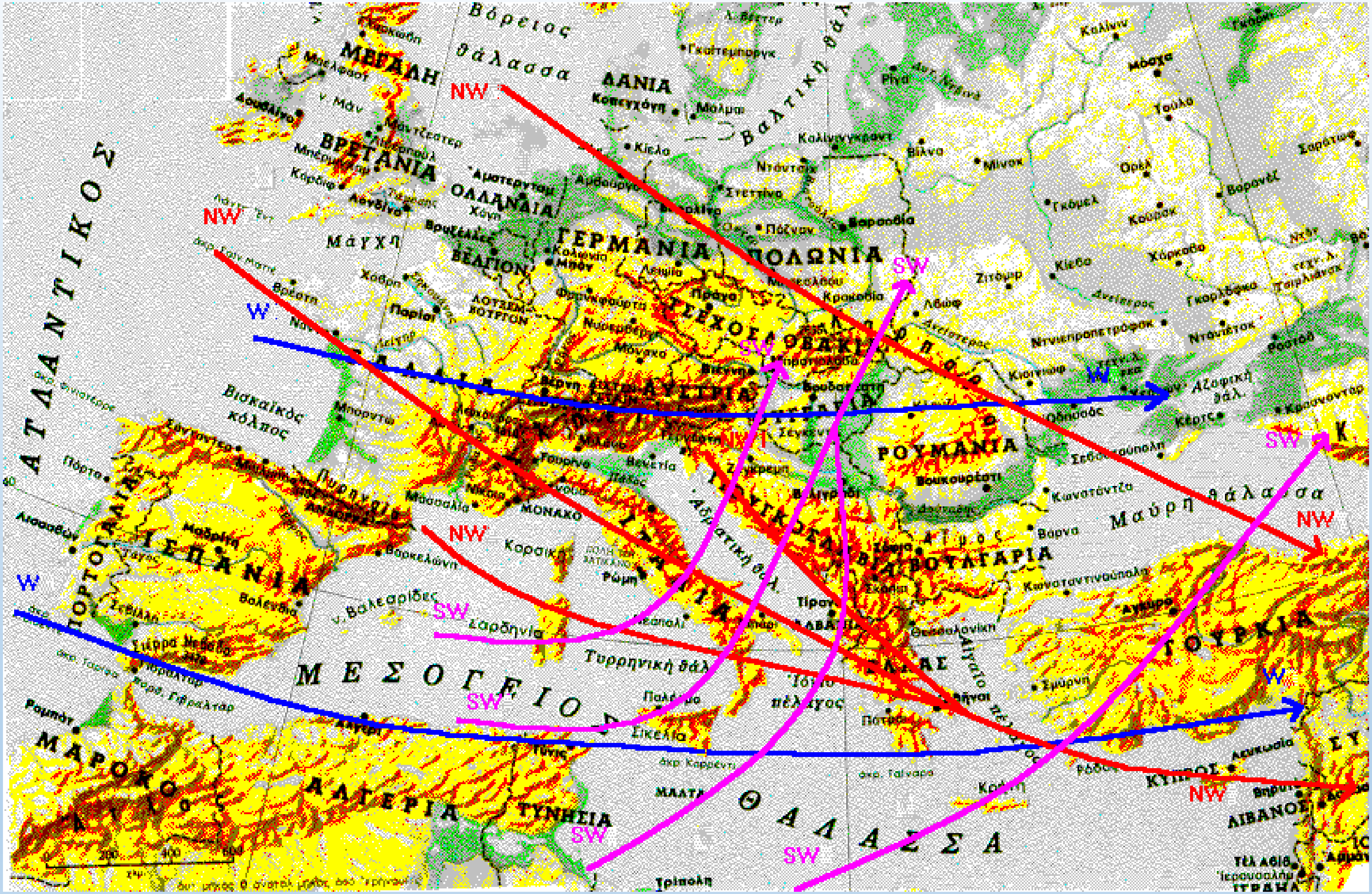
Prevention: flood damage prevention, avoiding construction of housing and industrial buildings in flood-prone areas, adapting future developments to the risk of floods and properly promoting land use and good forestry practices.

Protection: take constructive and non-constructive measures to reduce the chance of flooding and / or the effects of floods in specific areas.

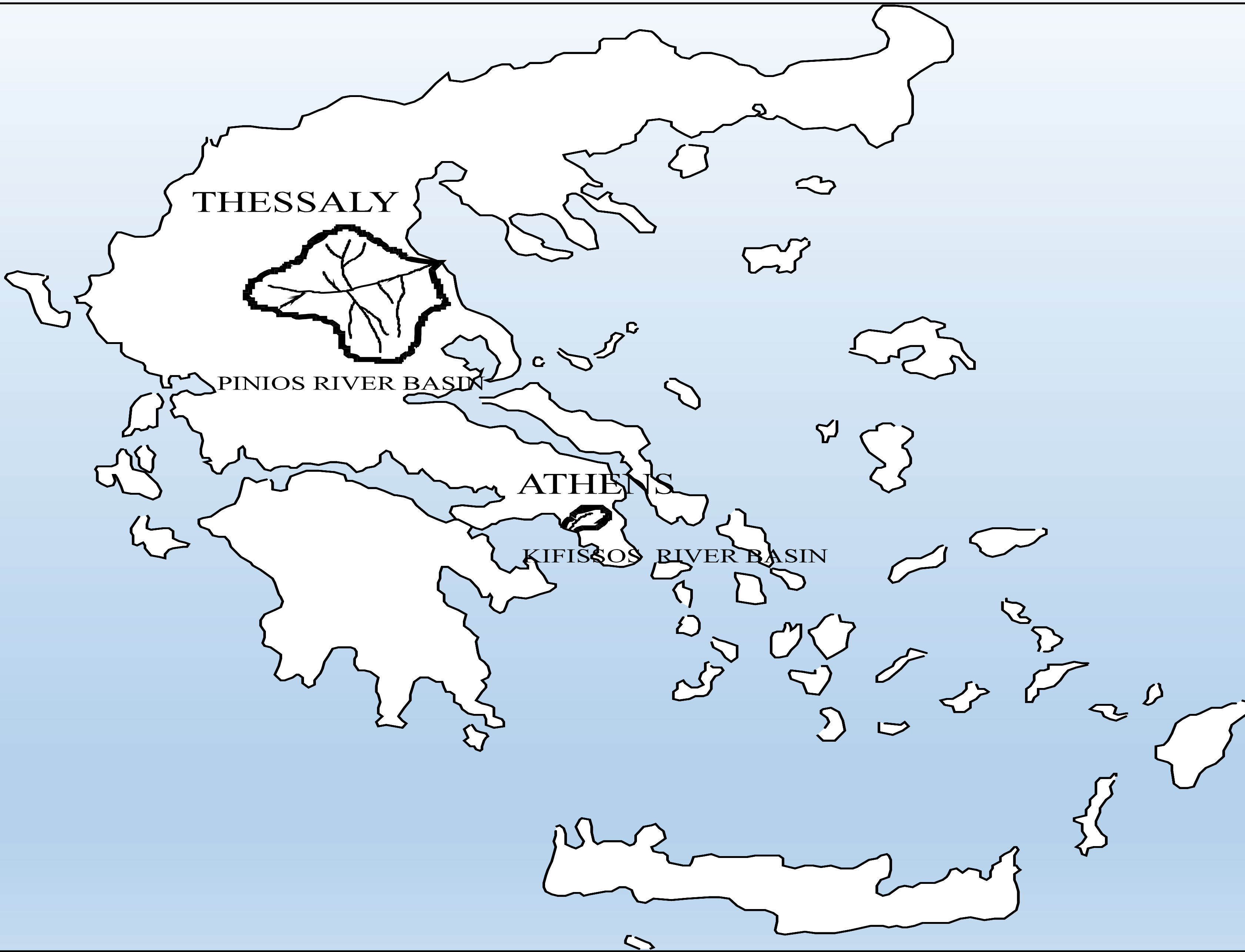
Readiness: informing the population about the dangers of floods and how to react in case of flooding.

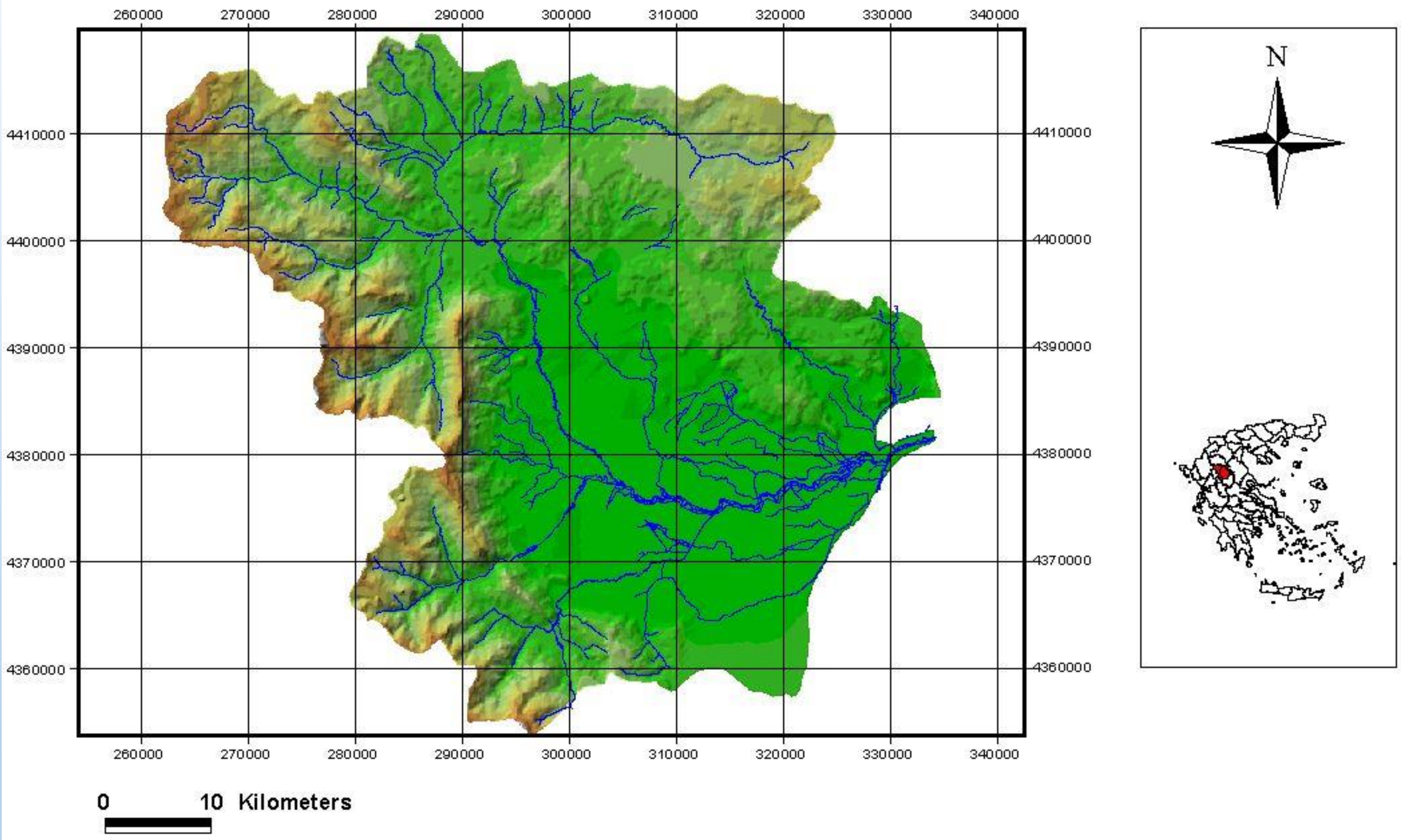
Emergencies: developing plans for dealing with them in the event of a flood.

Restoration and lesson-learning: returning to normal conditions as soon as possible and mitigation of both social and economic impacts on the affected population.



<u>MAIN TRAJECTORIES OF CYCLONIC WEATHER TYPES</u>


THESSALY
PINIOS RIVER BASIN
ATHENS
KIFISSOS RIVER BASIN



Ali-Efenti Basin

$$Pr = \frac{ð^3 P_t g^2 è ö h |Ê|^2 Z}{1024 \ln(2) ë^2 r^2}$$

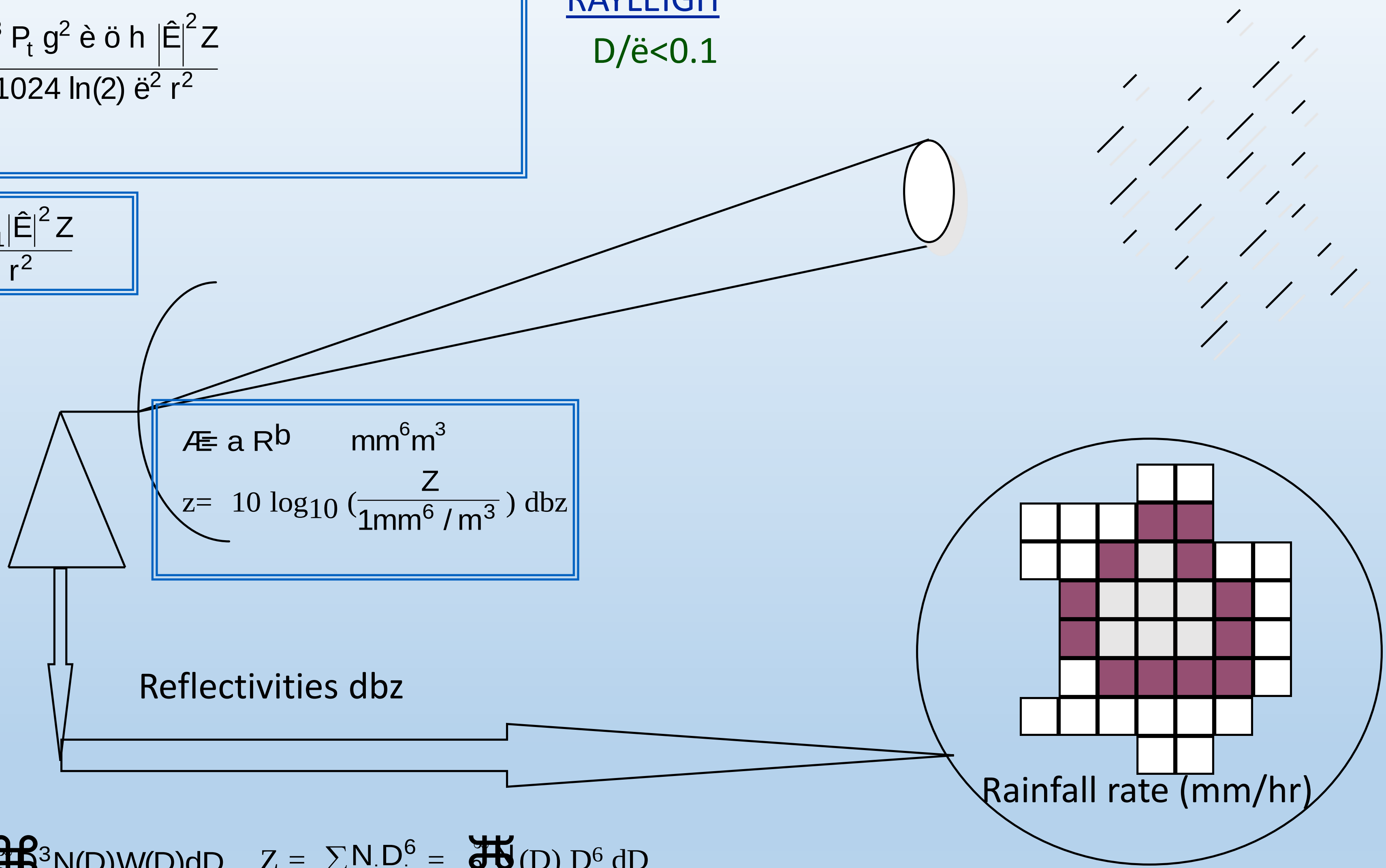
$$Pr = \frac{C_1 |Ê|^2 Z}{r^2}$$

RAYLEIGH

D/ë<0.1

$Æ = a R^b \quad mm^6 m^3$

$$z = 10 \log_{10} \left(\frac{Z}{1mm^6 / m^3}\right) dbz$$



$$R = \frac{ð}{6} ⌘ D^3 N(D) W(D) dD \qquad Z = \sum_i N_i D_i^6 = ⌘ N(D) D^6 dD$$

$N(D) = N_o e^{-ëD}, \quad ë = 4.1 R^{-0.21} \quad N_0 = 8000 / mm^6 m^3$

ANALYSIS AND PROCESSING OF RADAR DATA

INPUT REFLECTIVITY DATA

POLAR TO 2X2 AND 4X4 SQ.KM. GRID CONVERSION

SUPPRESSION OF GROUND CLUTTER

HOURLY INTEGRATION OF REFLECTIVITY DATA

DERIVATION AND USE OF Z-R RELATIONSHIP FOR CONVERSION TO RATE RAINFALL

HOURLY OUTLIER CHECK (INFLUENCE FUNCTION METHOD)

COLLECTION AND ANALYSIS OF HOURLY RAINGAGE DATA

ADJUSTMENT OF RADAR RAINFALL PATTERNS

BRANDES METHOD

KALMAN FILTER TECHNIQUES

GENERATION OF GRAPHS REPRESENTING THE RADAR RAINFALL FIELDS

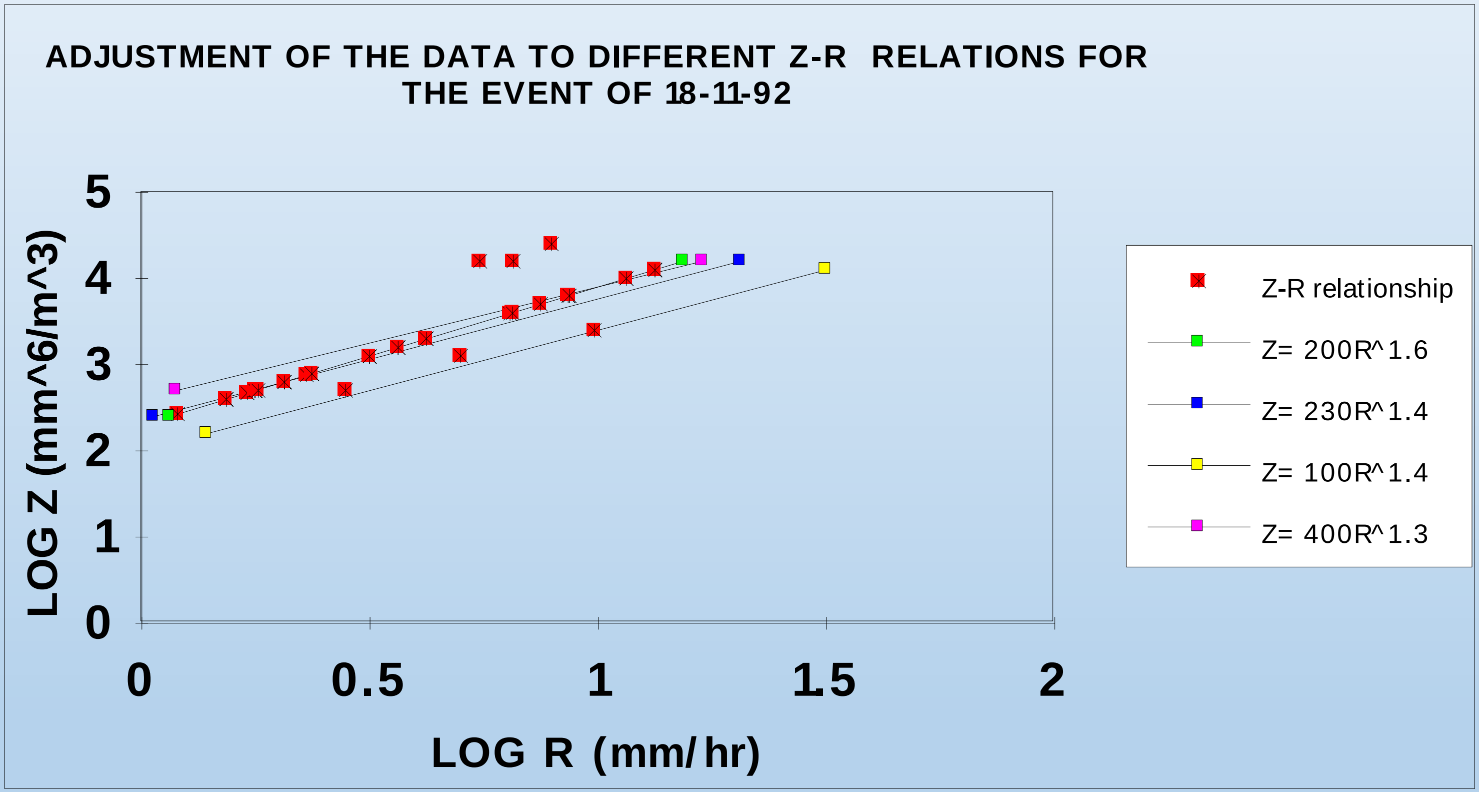
FLOOD FORECASTING (SHORT-TERM RAINFALL FORECASTING)

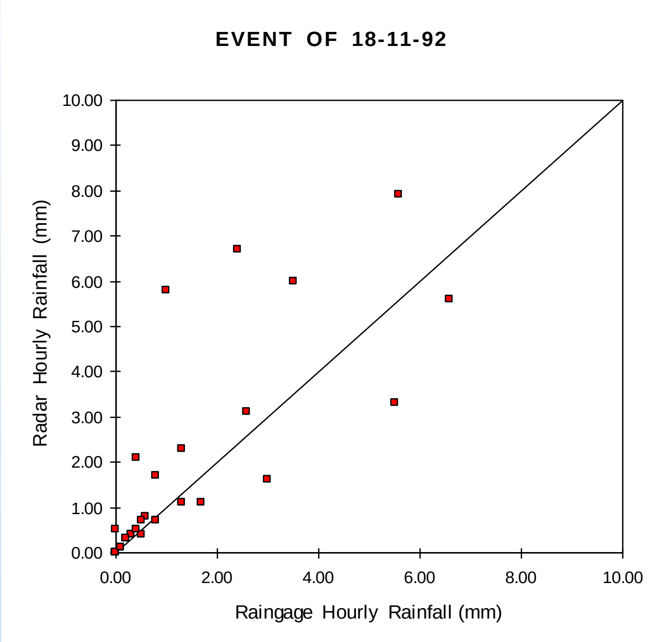
Æ= a R^b $mm^6 m^3$

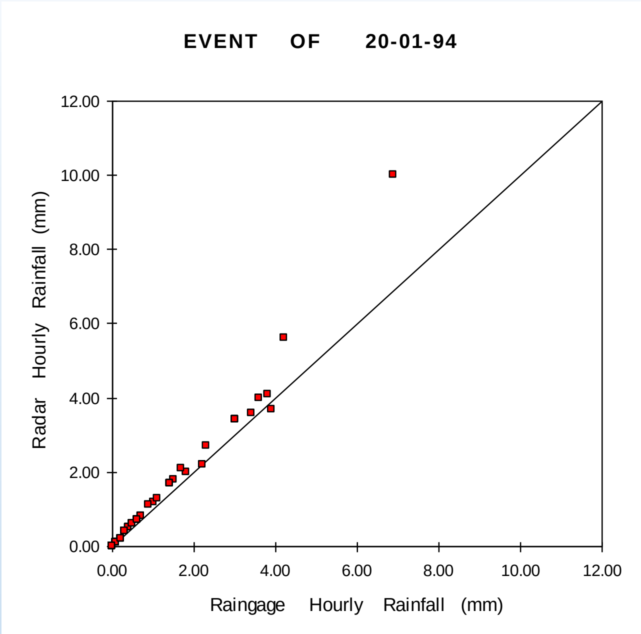
$$z = 10 \log_{10} \left(\frac{Z}{1 mm^6 / m^3} \right) dbz$$

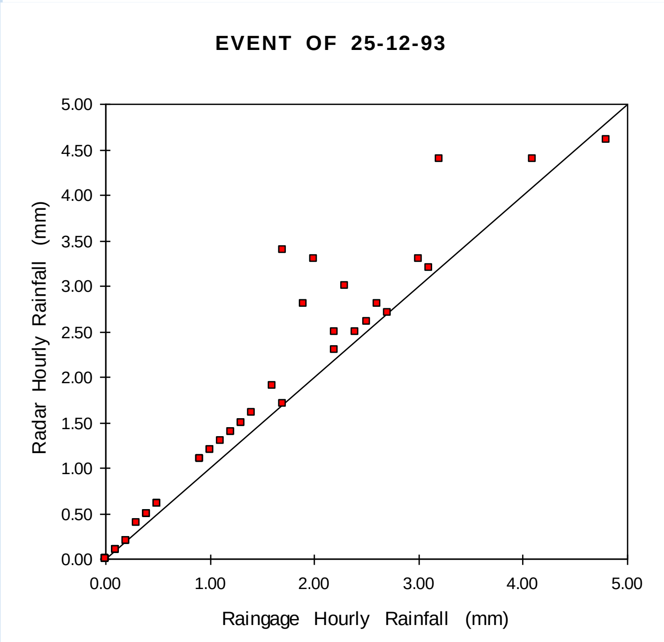
a =175-210

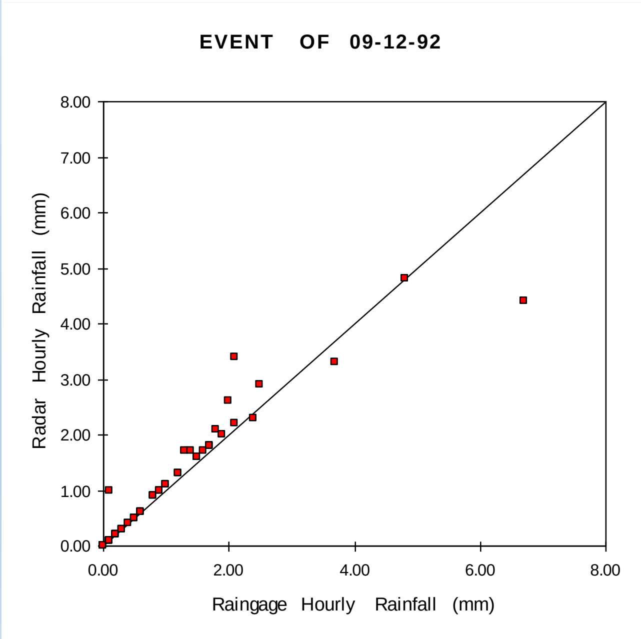
b=1.2-1.6




EVENT OF 18-11-92
Radar Hourly Rainfall (mm)
Raingage Hourly Rainfall (mm)
0.00
2.00
4.00
6.00
8.00
10.00
1.00
3.00
5.00
7.00
9.00

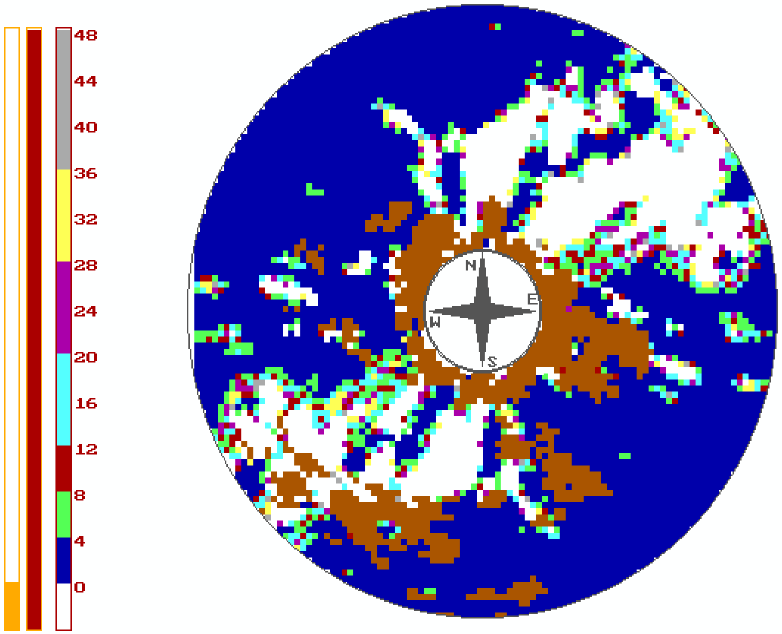

EVENT OF 20-01-94
Radar Hourly Rainfall (mm)
Raingage Hourly Rainfall (mm)
0.00
2.00
4.00
6.00
8.00
10.00
12.00


EVENT OF 25-12-93
Radar Hourly Rainfall (mm)
Raingage Hourly Rainfall (mm)
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00

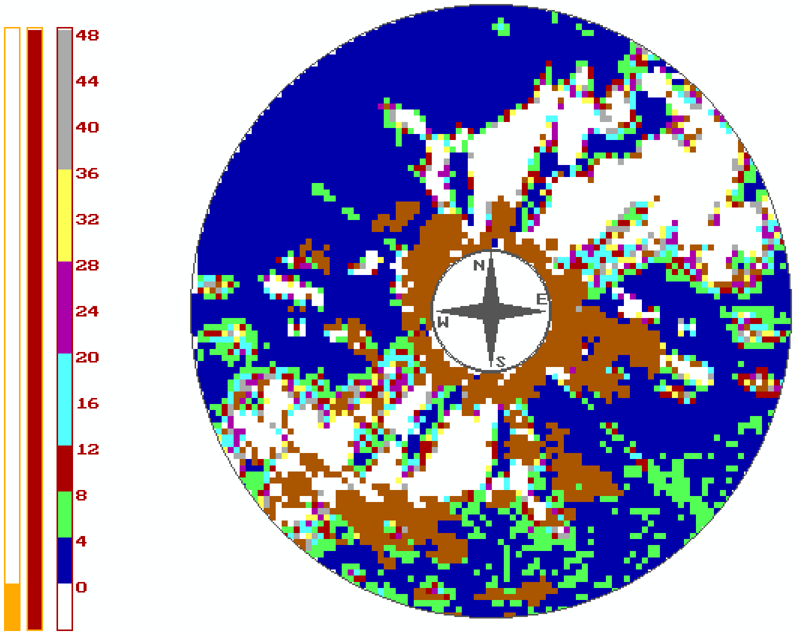

EVENT OF 09-12-92
Radar Hourly Rainfall (mm)
Raingage Hourly Rainfall (mm)
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00

EVENT OF 18-11-92 (TIME 11:00-12:00)

UNCALIBRATED RADAR RAINFALL FIELD

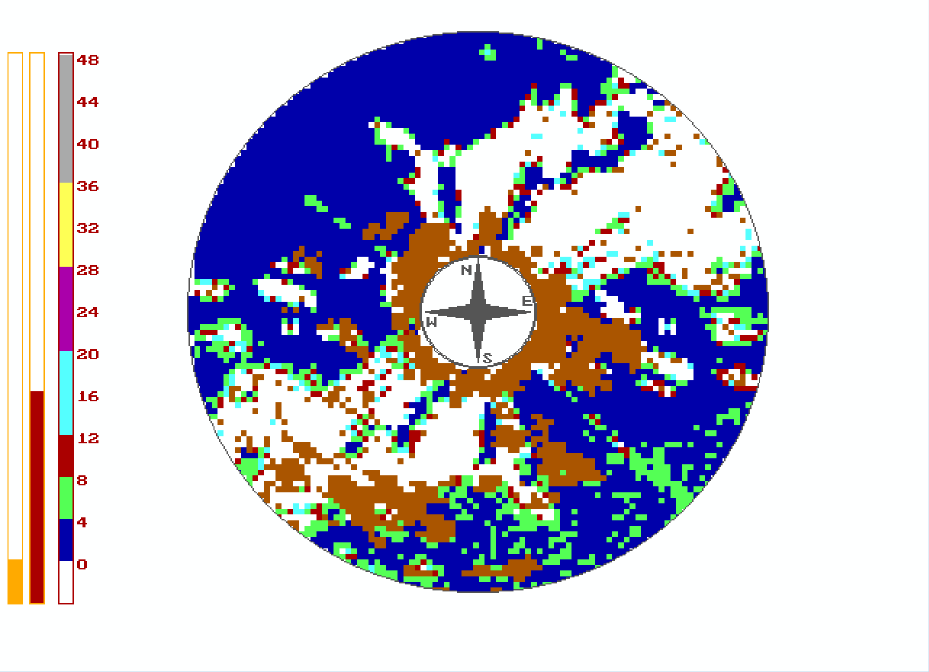


CALIBRATED RADAR RAINFALL FIELD

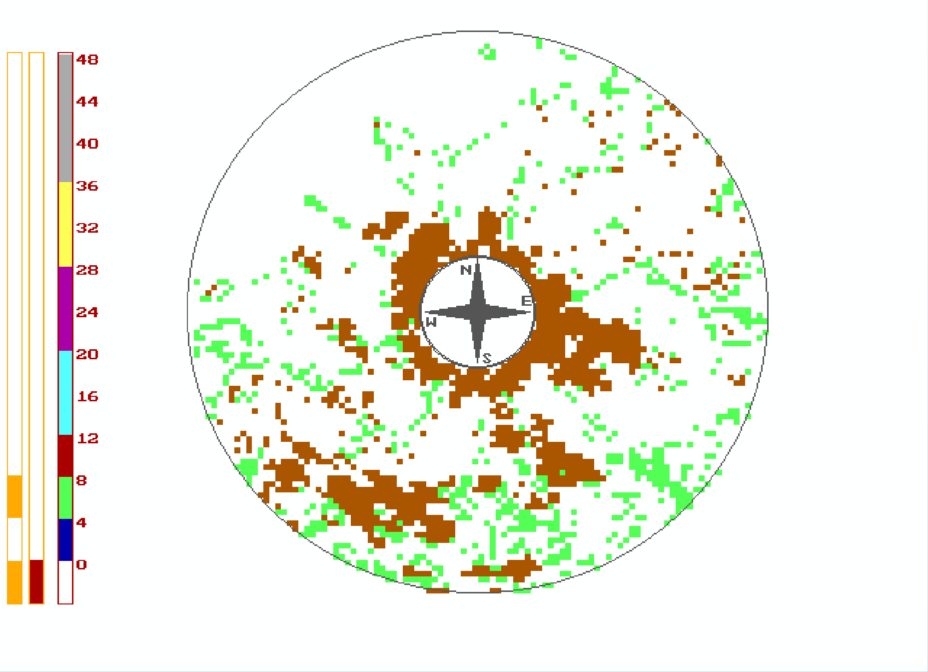


EVENT OF 18-11-92 (TIME 11:00-12:00)

RADAR RAINFALL FIELD (R<16mm)

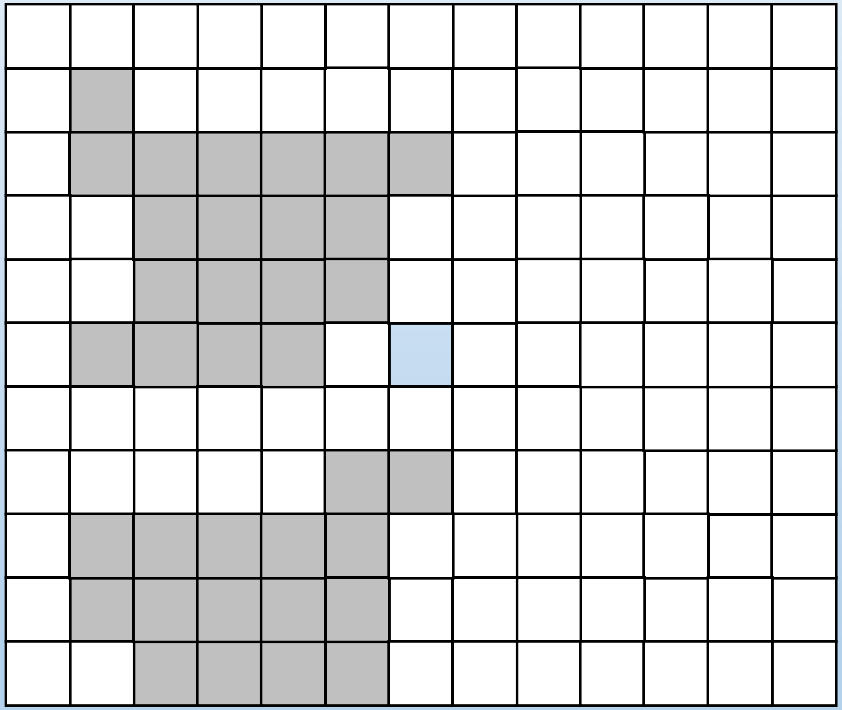


RADAR RAINFALL FIELD (4<R<8mm)

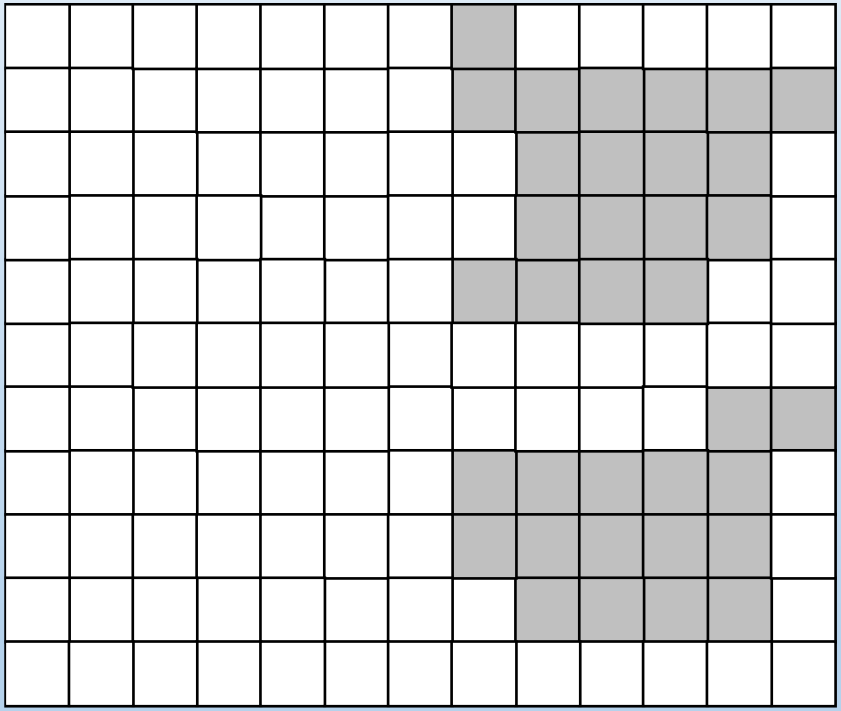


LINEAR EXTRAPOLATION OF THE CENTROIDS OF FEATURES OF RADAR RAINFALL FIELDS

RADAR FIELD AT TIME T(0)

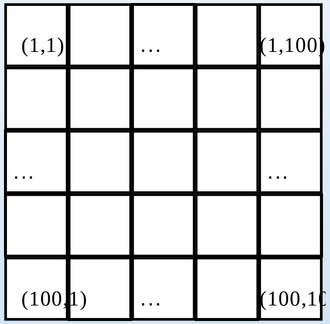


RADAR FIELD AT TIME T(1)

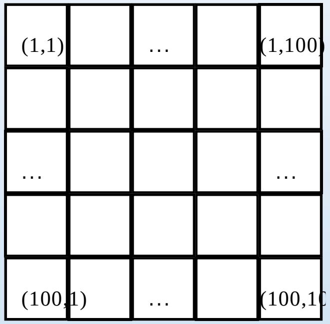


CROSS-CORELATION BETWEEN TWO RADAR FIELDS AT TIMES T(0) AND T(1)

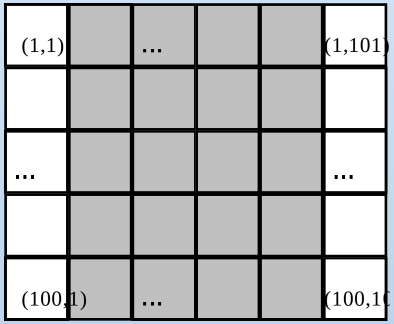
RADAR FIELD AT TIME T(0)



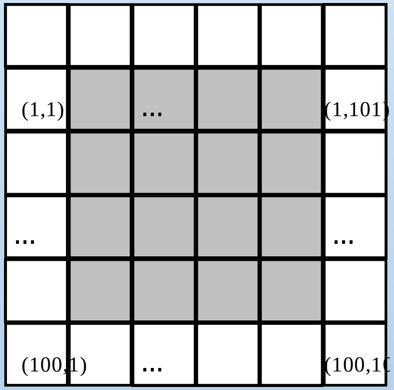
RADAR FIELD AT TIME T(1)



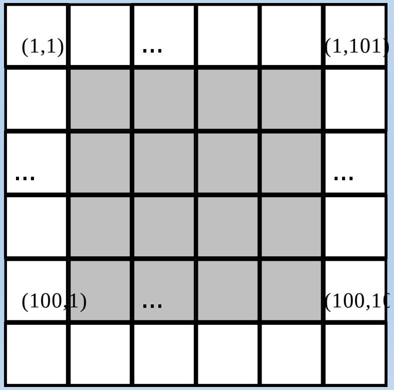
RADAR FIELD SHIFTED RIGHT AT TIME T(1)



RADAR FIELD SHIFTED UP AT TIME T(1)



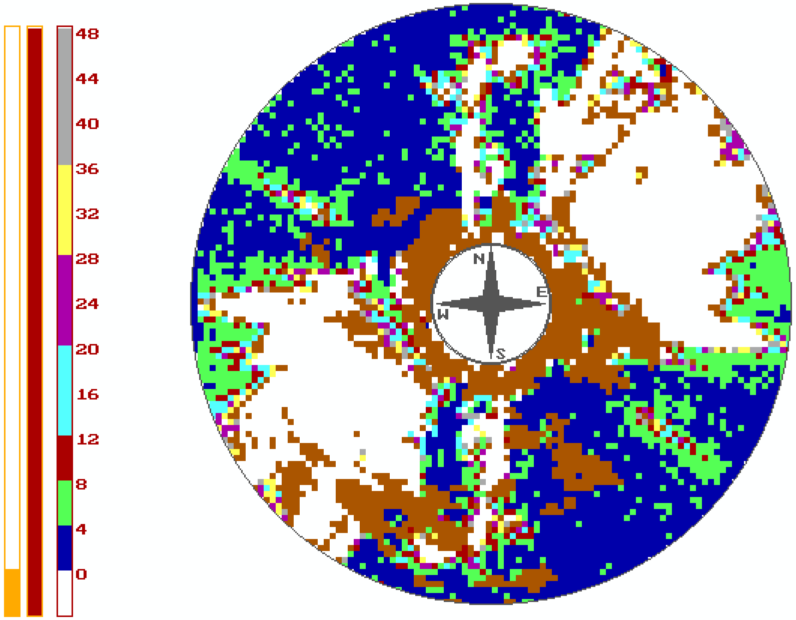
RADAR FIELD SHIFTED DOWN AT TIME (T1)



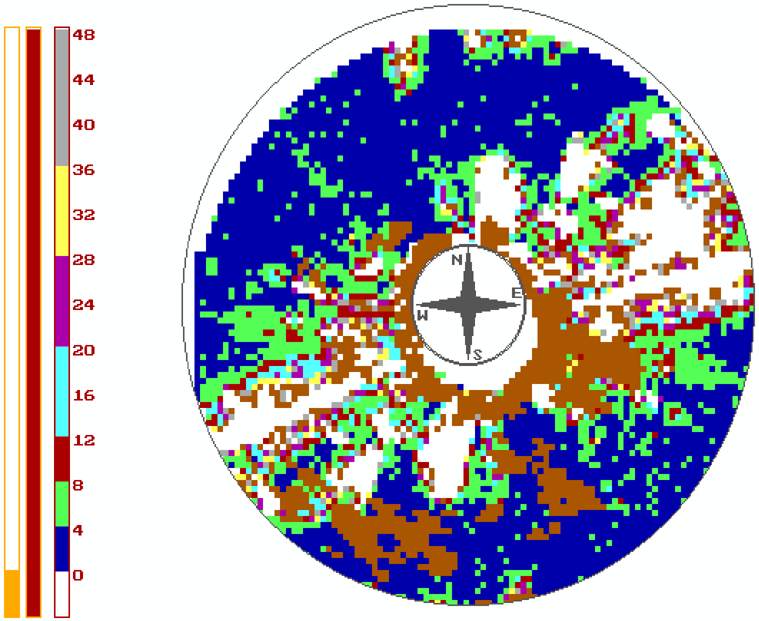
A/A	U/D	L/R	SÁMPLÅ SIZE
0	0	0	10000
1	0	1	9900
2	0	-1	9900
3	1	0	9900
4	1	-1	9801
5	3	-1	9603
6	-1	2	9702
7	0	2	9800
8	-1	0	9900
9	-1	1	9801

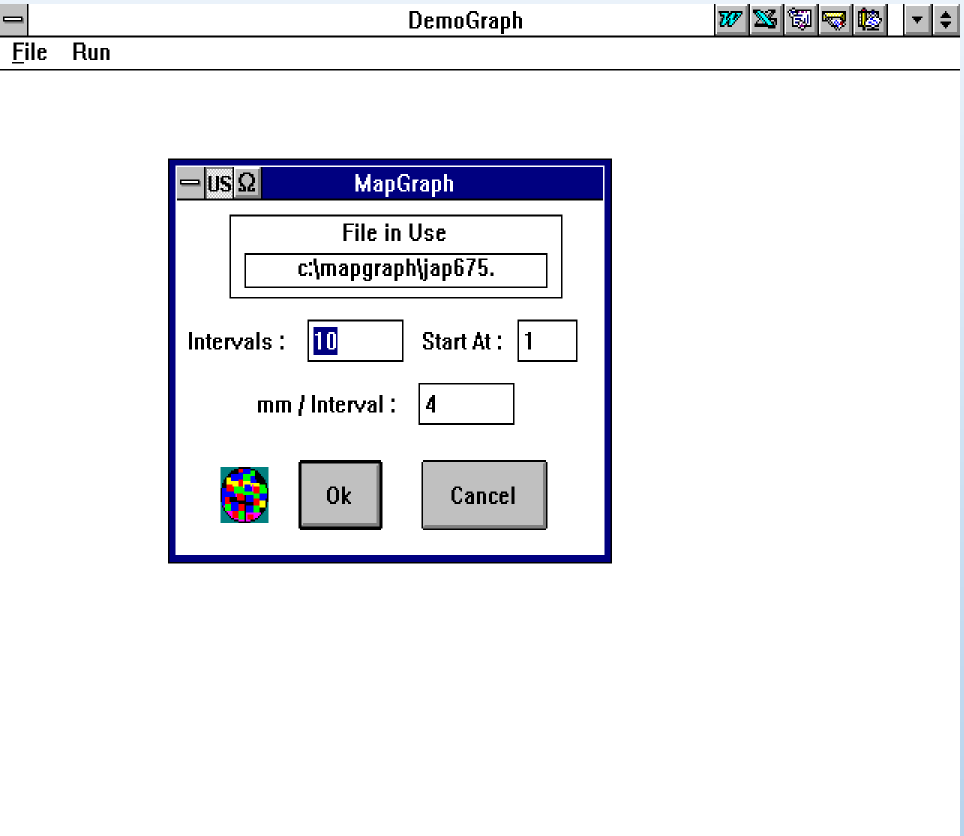
Event 18-11-92

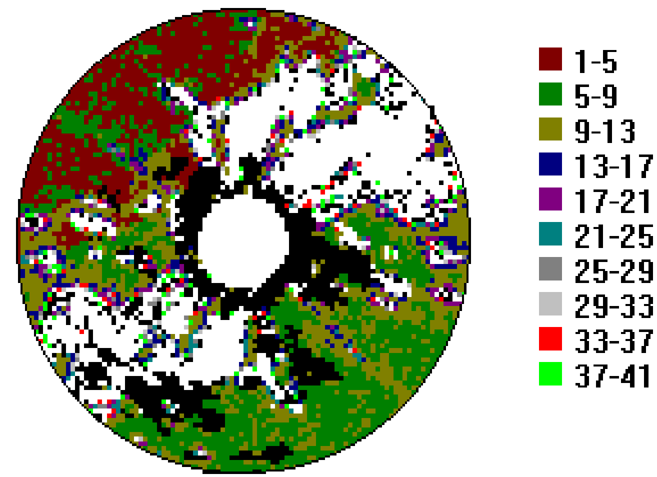
Observed



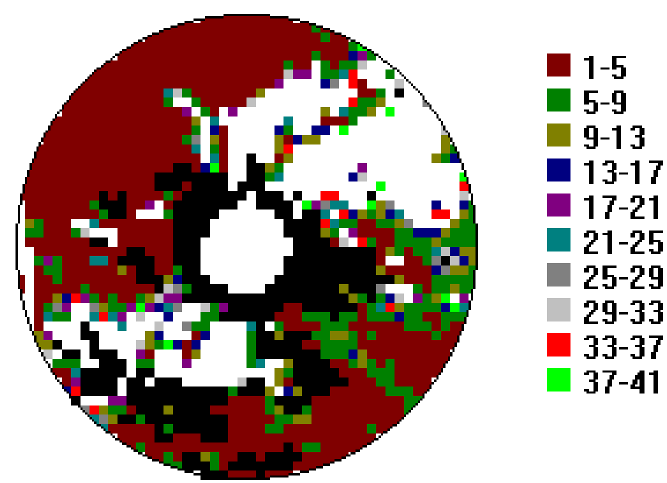
Forecasted (1.5 hours)




DemoGraph
File
Run
MapGraph
File in Use
c:\mapgraph\jap675.
Intervals :
10
Start At :
1
mm / Interval :
4
Ok
Cancel


1-5
5-9
9-13
13-17
17-21
21-25
25-29
29-33
33-37
37-41

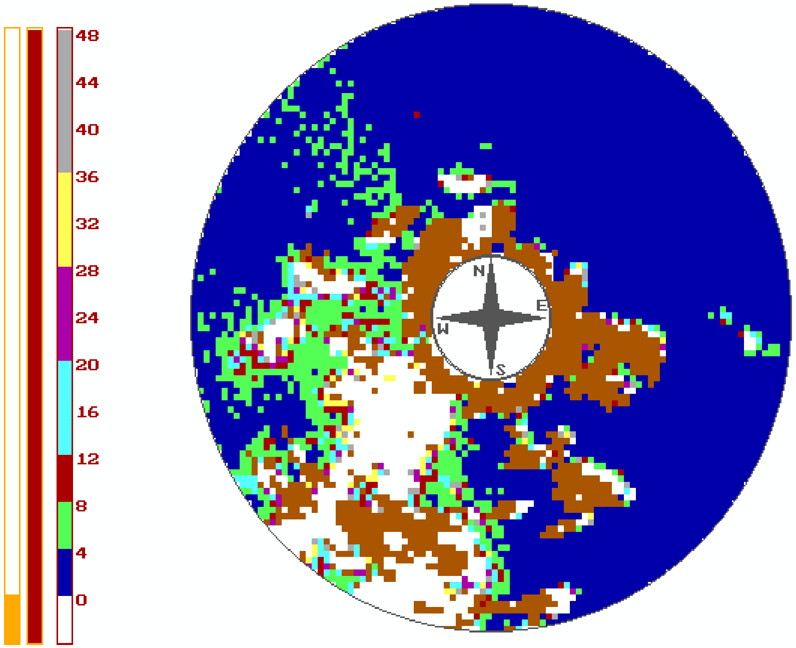
(á)


1-5
5-9
9-13
13-17
17-21
21-25
25-29
29-33
33-37
37-41

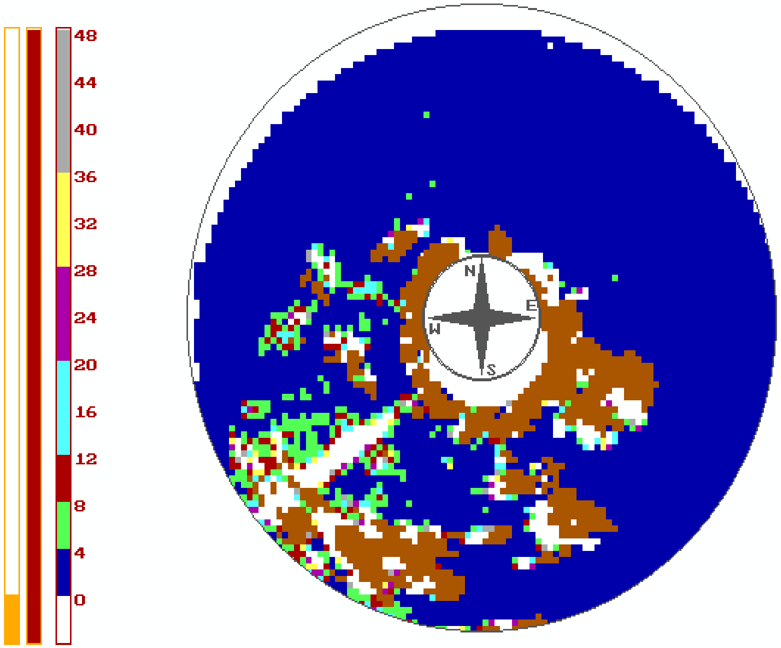
(â)

Event 12-11-92

Observed



Forecasted (35 min)



A RAINFALL - RUNOFF LUMPED MODEL (HEC1F)

INPUT PARAMETERS

1. BASE FLOW
2. LOSSES (INITIAL AND CONSTANT)
3. SNYDER COEFFICIENTS (TP,CP)

- HEC1F MODEL WITH RAINGAGE DATA

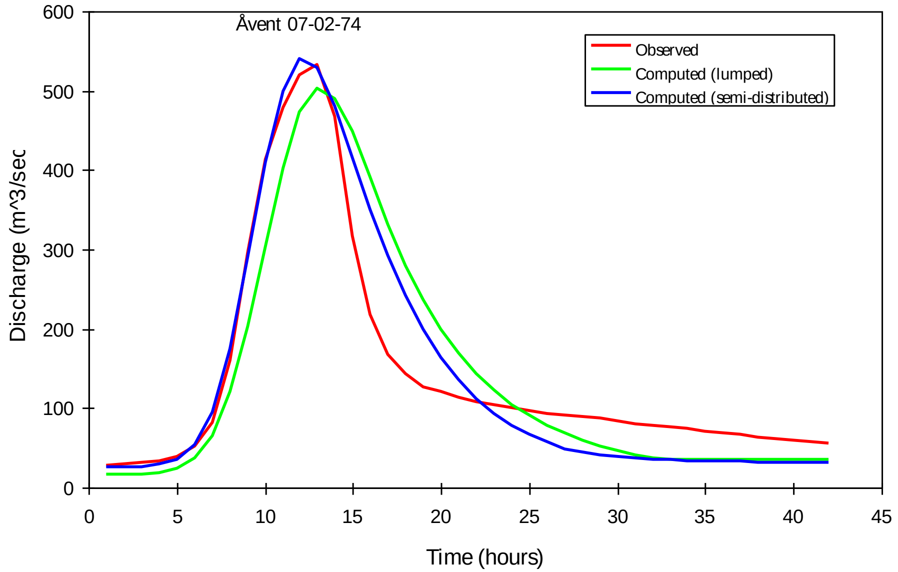
  CALIBRATION

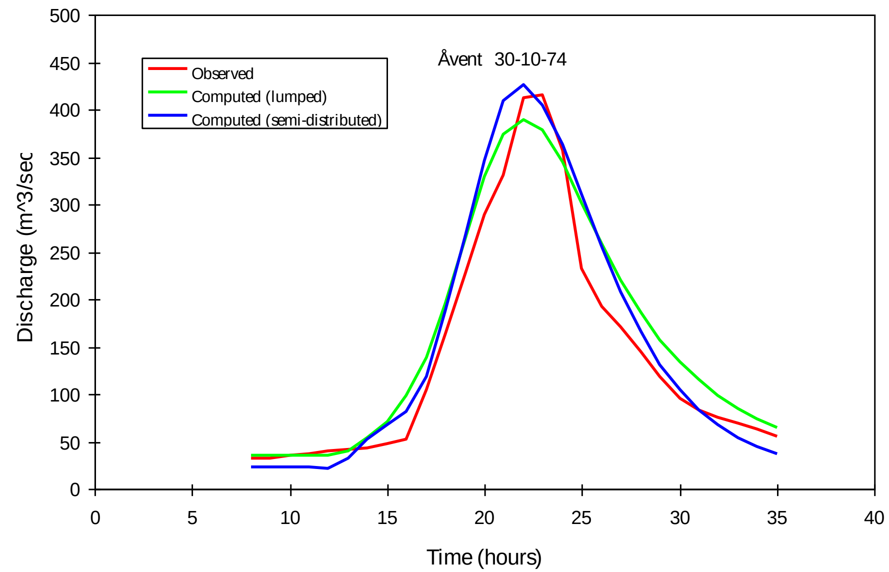
  SIMULATION
  SHORT TERM FORECASTING 2,4,6 HOURS

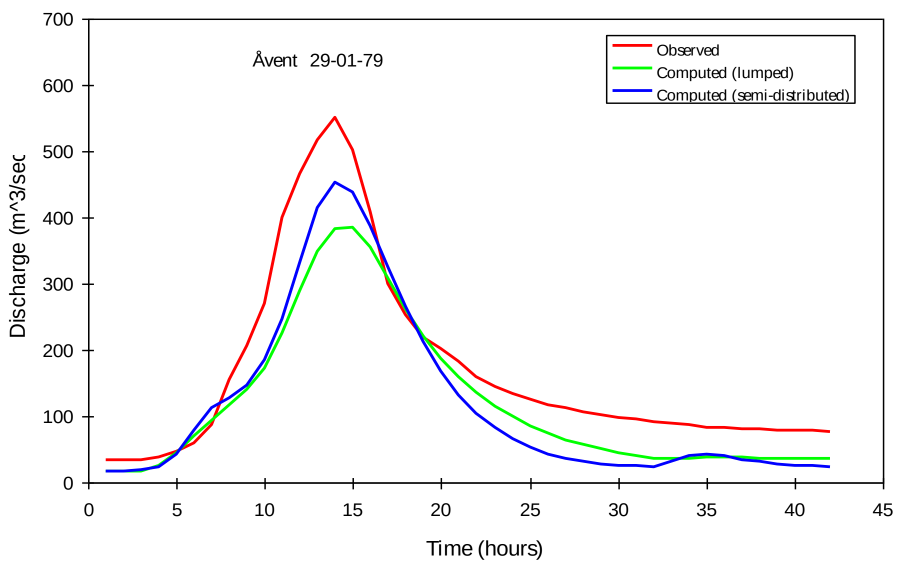
- HEC1F MODEL WITH RADAR DATA

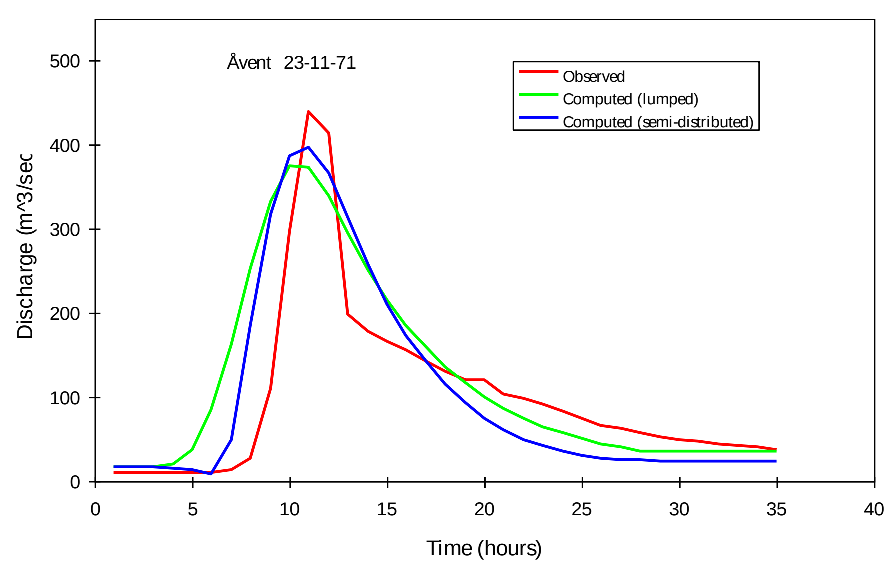
  CALIBRATION

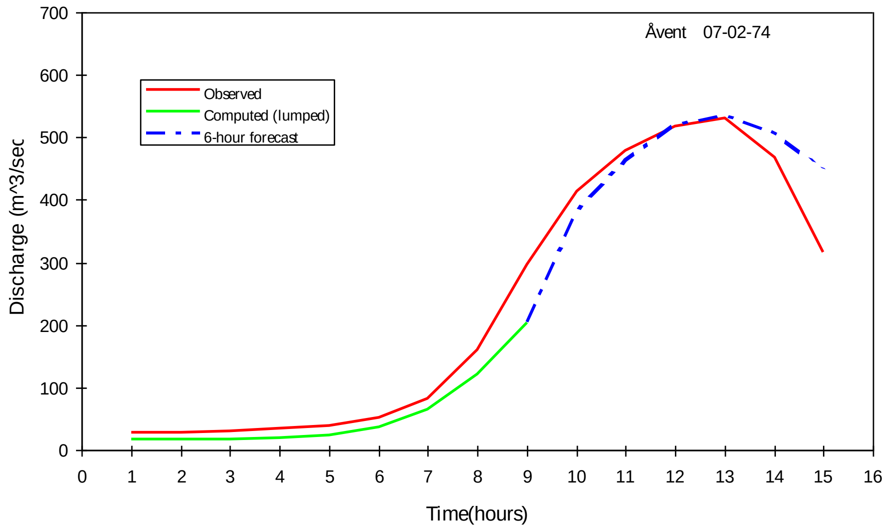
  SIMULATION
  SHORT TERM FORECASTING 2,4,6 HOURS

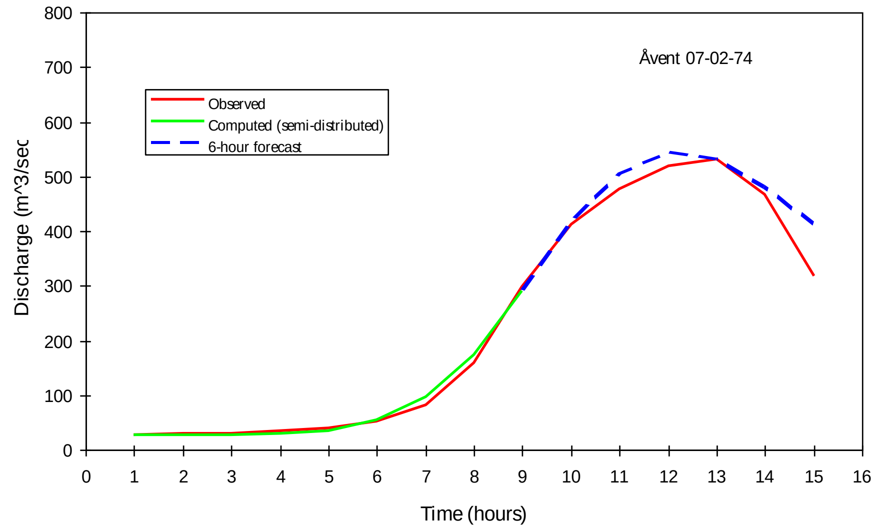

Åvent 07-02-74
Observed
Computed (lumped)
Computed (semi-distributed)
Discharge (m^3/sec
Time (hours)
0 100 200 300 400 500 600
0 5 10 15 20 25 30 35 40 45

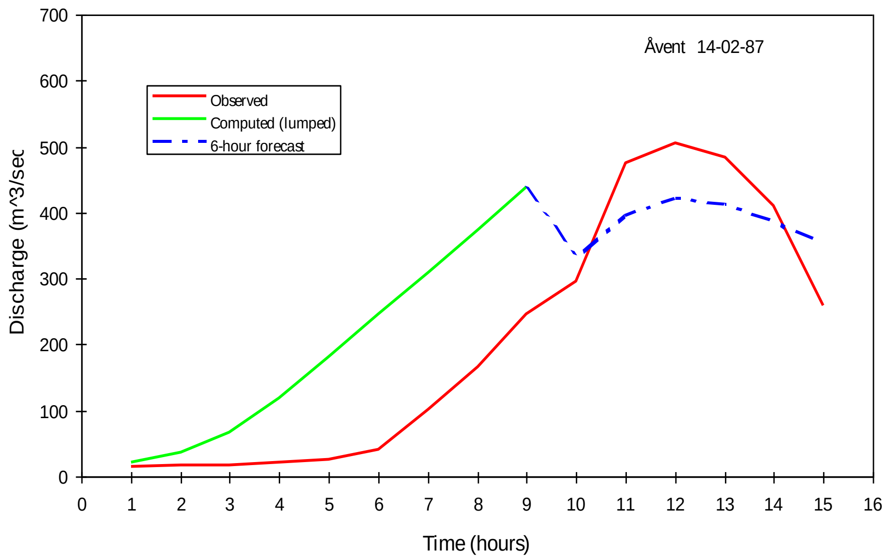

Åvent 30-10-74
Observed
Computed (lumped)
Computed (semi-distributed)
Discharge (m^3/sec
Time (hours)
0 50 100 150 200 250 300 350 400 450 500
0 5 10 15 20 25 30 35 40

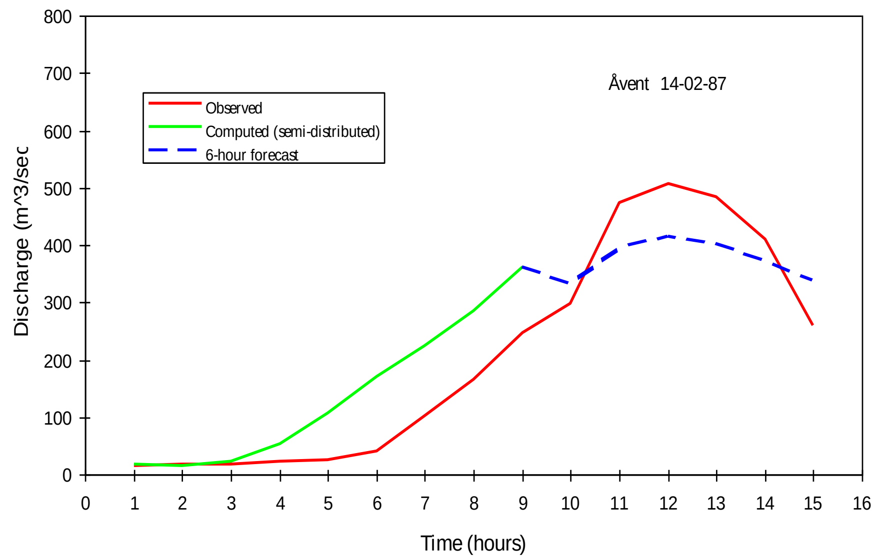

Åvent 29-01-79
Observed
Computed (lumped)
Computed (semi-distributed)
Discharge (m^3/sec
Time (hours)
0 100 200 300 400 500 600 700
0 5 10 15 20 25 30 35 40 45

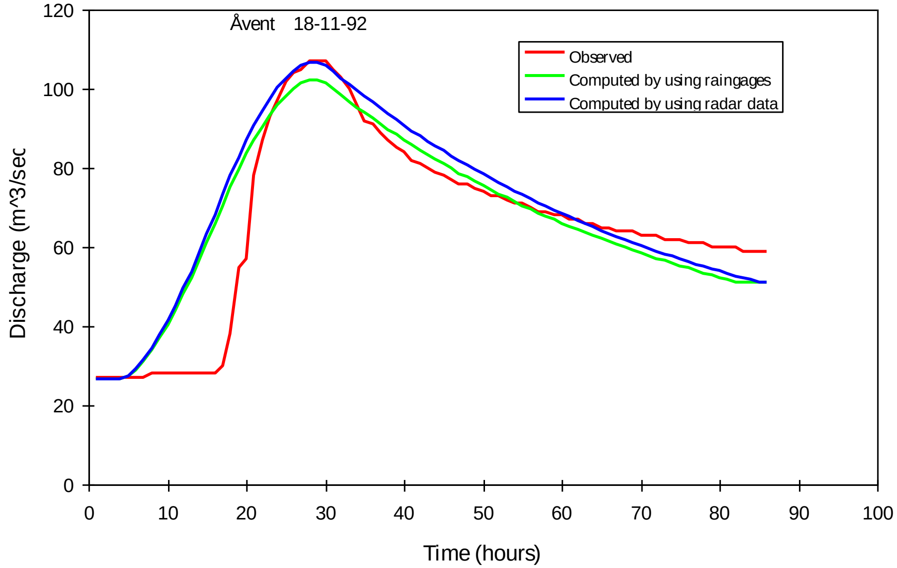

Åvent 23-11-71
Observed
Computed (lumped)
Computed (semi-distributed)
Discharge (m^3/sec
Time (hours)
0 100 200 300 400 500
0 5 10 15 20 25 30 35 40

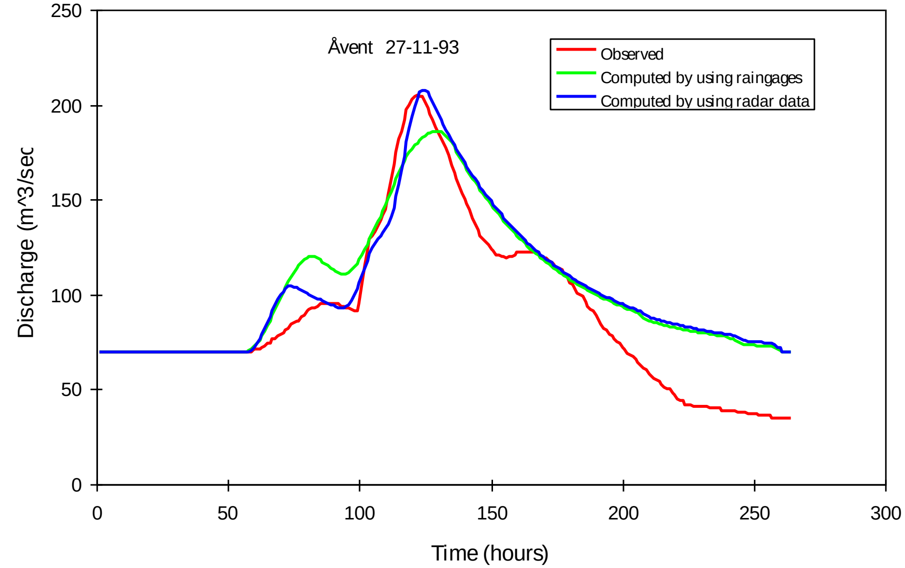

Åvent 07-02-74
Observed
Computed (lumped)
6-hour forecast
Discharge (m^3/sec
Time(hours)

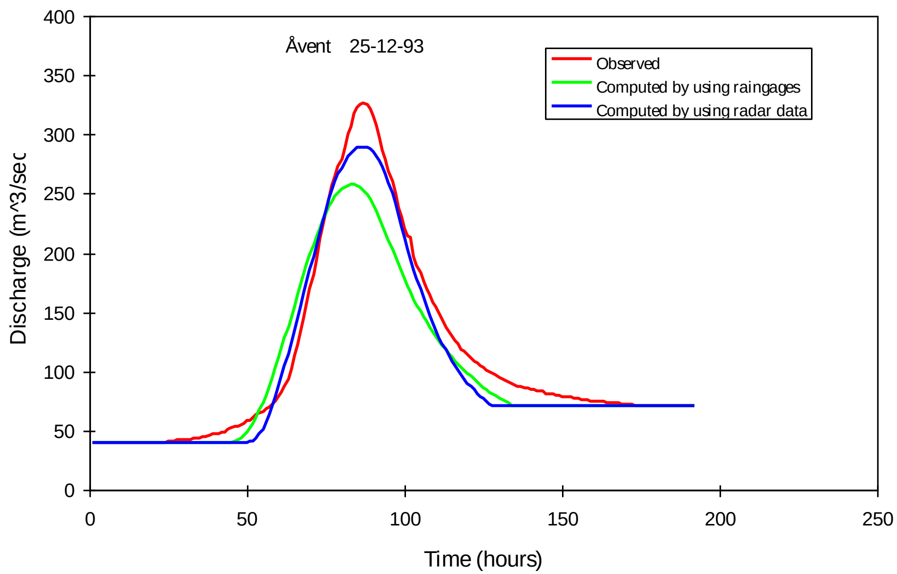

Åvent 07-02-74
Observed
Computed (semi-distributed)
6-hour forecast
Discharge (m^3/sec
Time (hours)

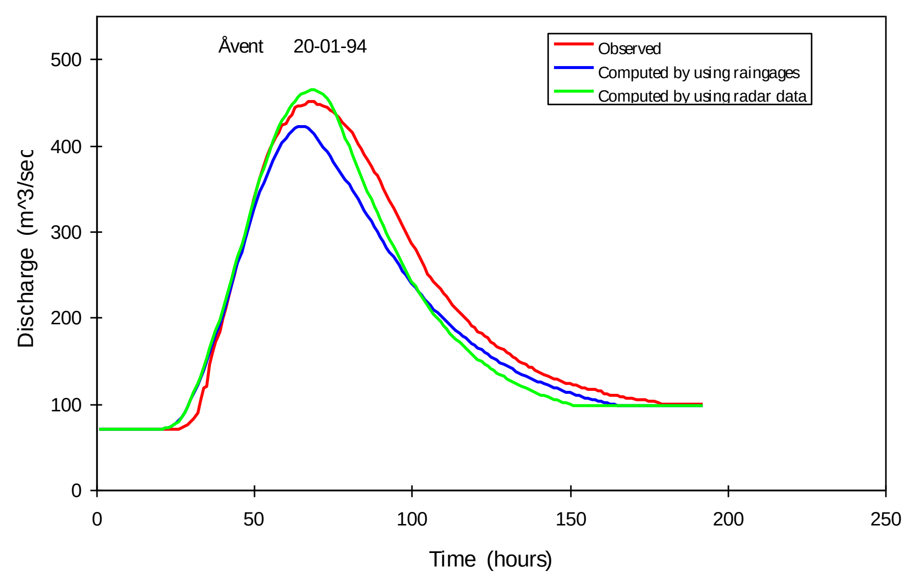

Åvent 14-02-87
Observed
Computed (lumped)
6-hour forecast
Discharge (m^3/sec
Time (hours)

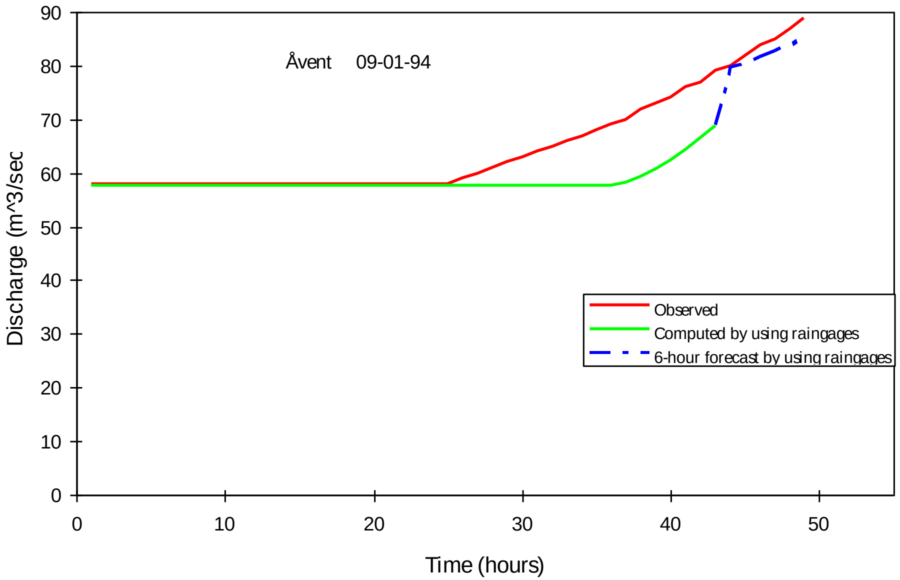

Åvent 14-02-87
Observed
Computed (semi-distributed)
6-hour forecast
Discharge (m^3/sec
Time (hours)

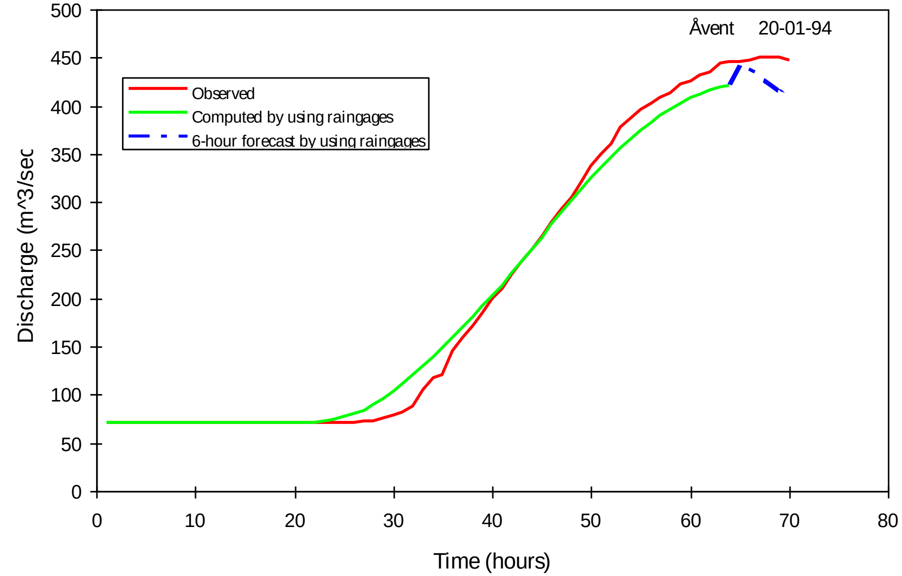

Åvent 18-11-92
Observed
Computed by using raingages
Computed by using radar data
Discharge (m^3/sec
Time (hours)
0
20
40
60
80
100
120
0
10
20
30
40
50
60
70
80
90
100

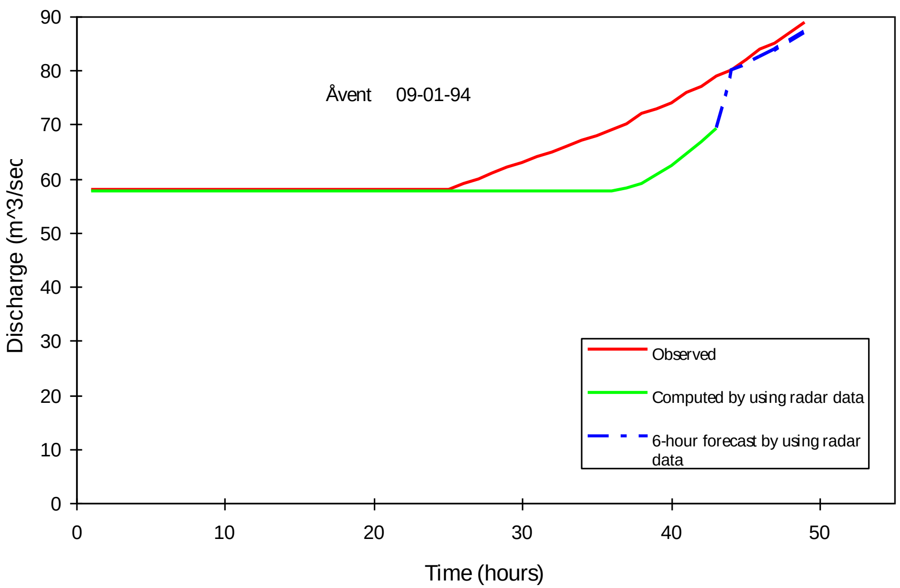

Åvent 27-11-93
Observed
Computed by using raingages
Computed by using radar data
Discharge (m^3/sec
Time (hours)
0
50
100
150
200
250
0
50
100
150
200
250
300

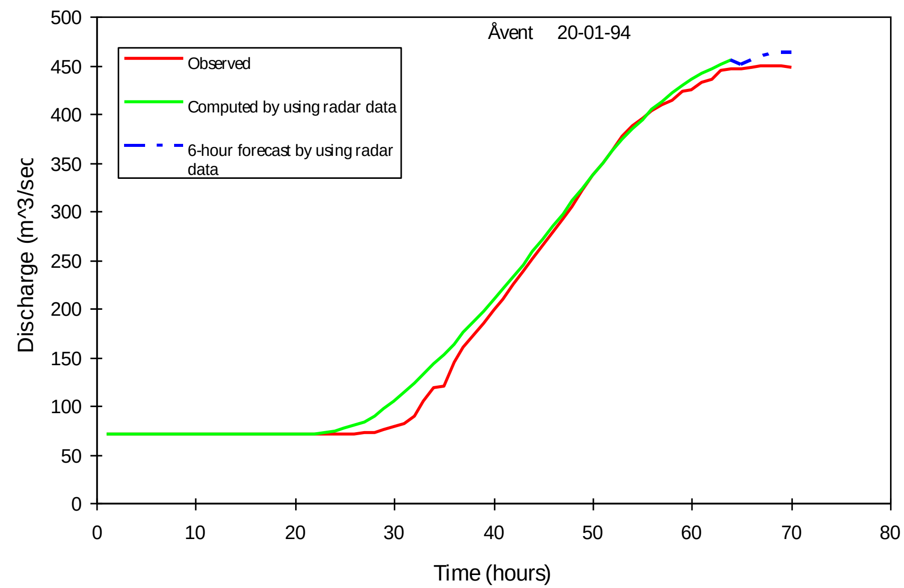

Åvent 25-12-93
Observed
Computed by using raingages
Computed by using radar data
Discharge (m^3/sec
Time (hours)
0
50
100
150
200
250
300
350
400
0
50
100
150
200
250

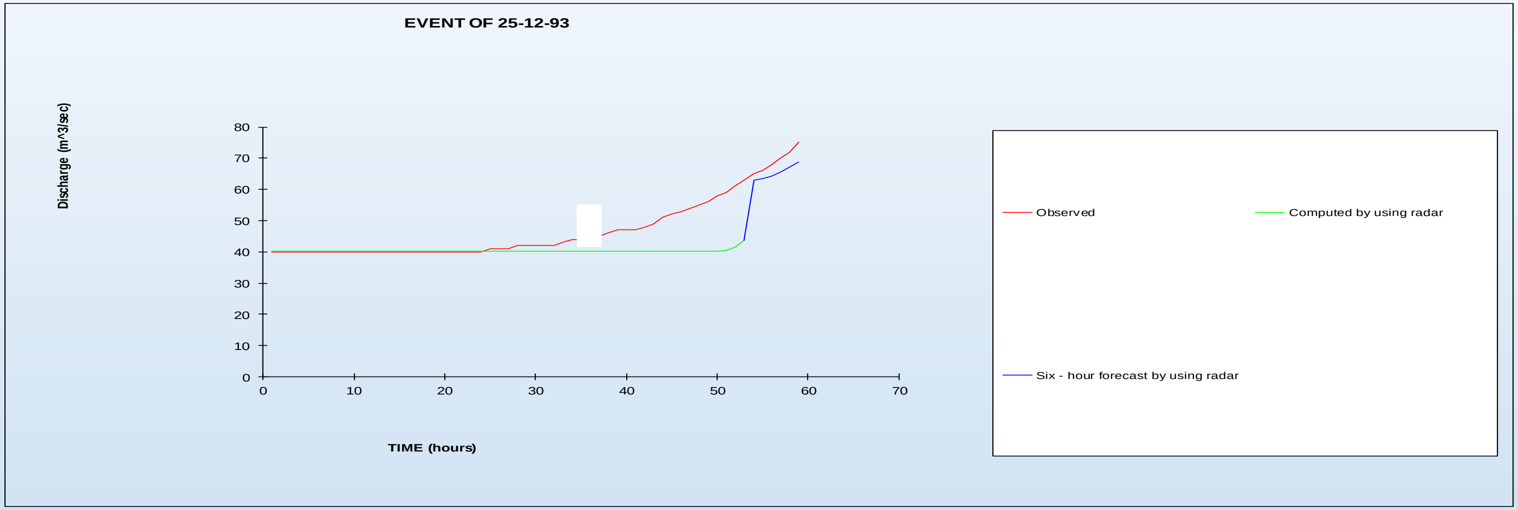

Åvent 20-01-94
Observed
Computed by using raingages
Computed by using radar data
Discharge (m^3/sec
Time (hours)
0
100
200
300
400
500
0
50
100
150
200
250

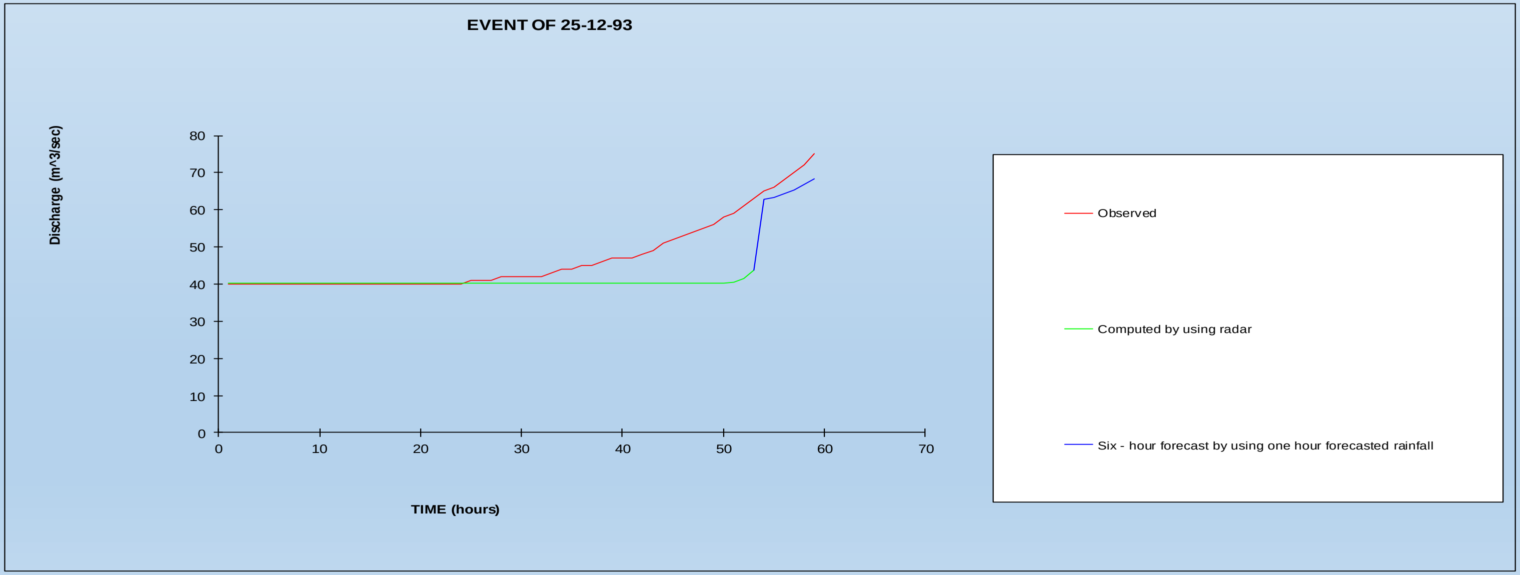

Åvent 09-01-94
Observed
Computed by using raingages
6-hour forecast by using raingages
Discharge (m^3/sec
Time (hours)

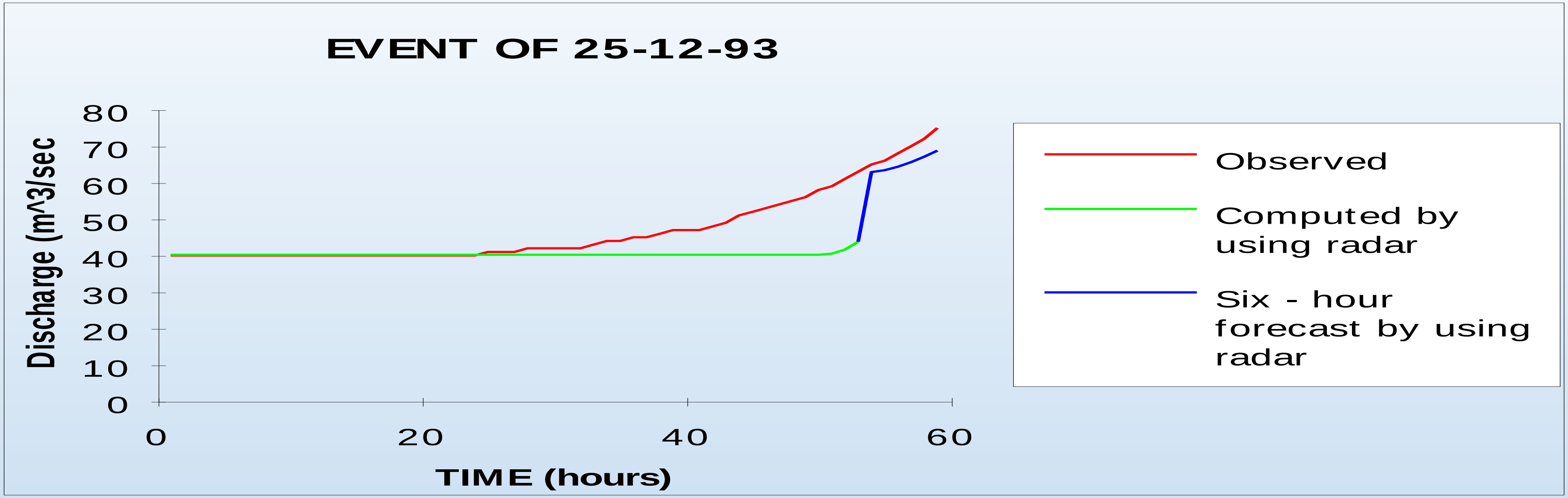

Åvent 20-01-94
Observed
Computed by using raingages
6-hour forecast by using raingages
Discharge (m^3/sec
Time (hours)

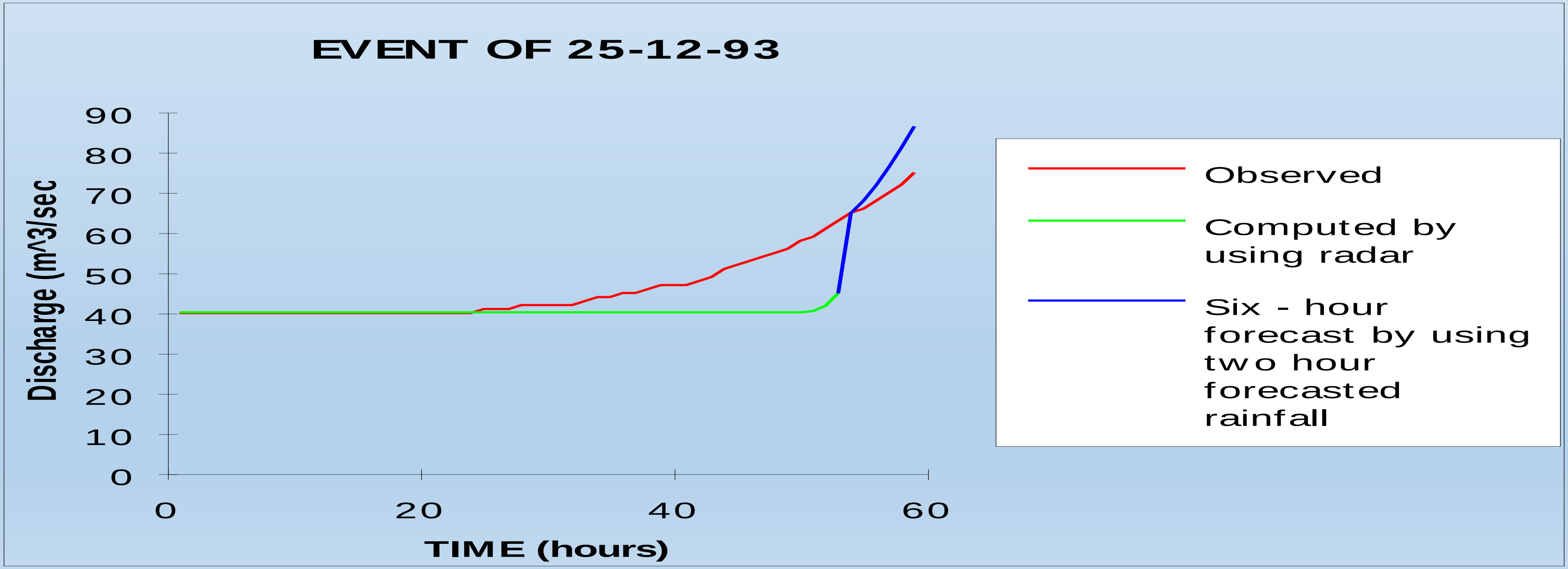

Åvent 09-01-94
Observed
Computed by using radar data
6-hour forecast by using radar data
Discharge (m^3/sec
Time (hours)

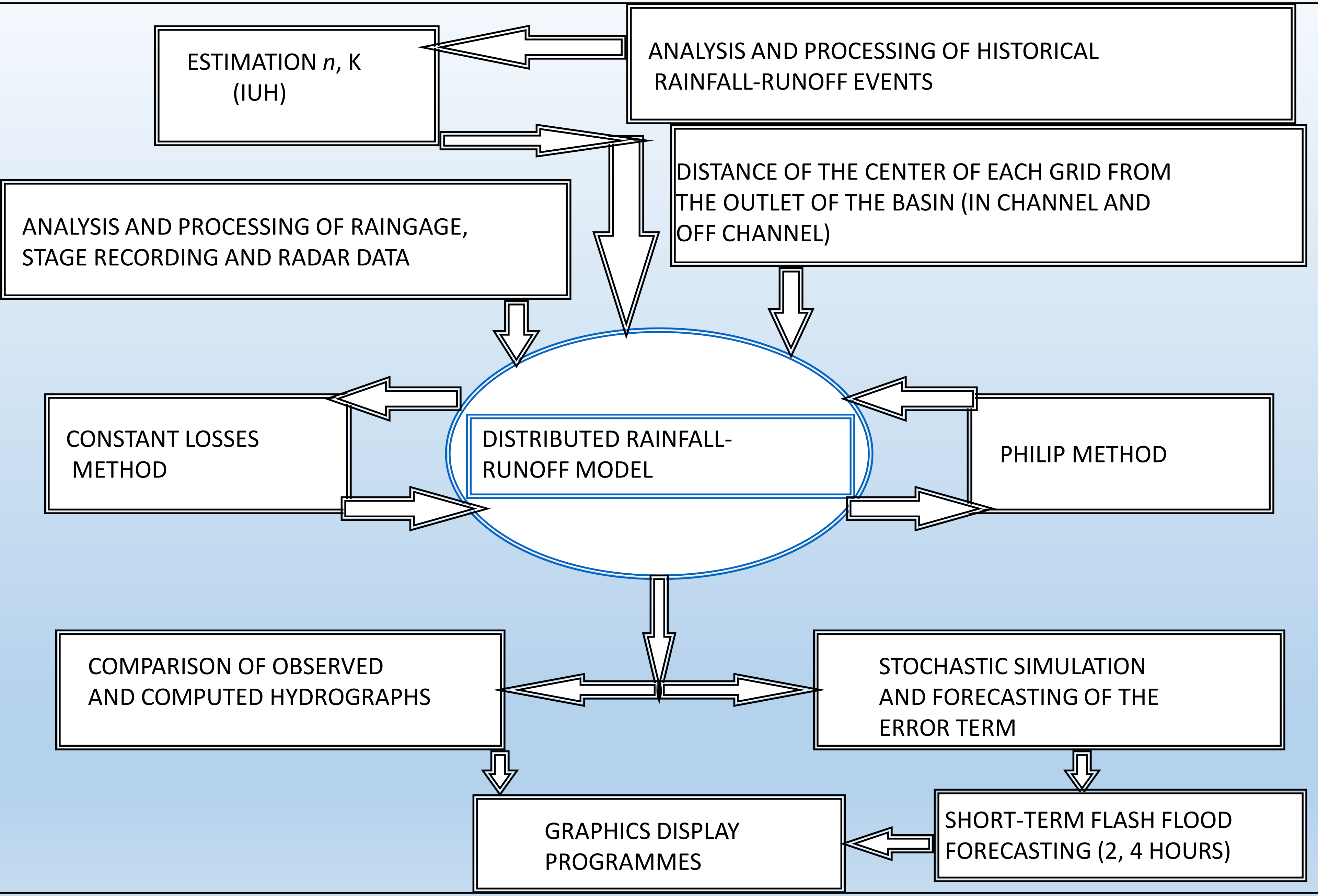

Åvent 20-01-94
Observed
Computed by using radar data
6-hour forecast by using radar data
Discharge (m^3/sec
Time (hours)

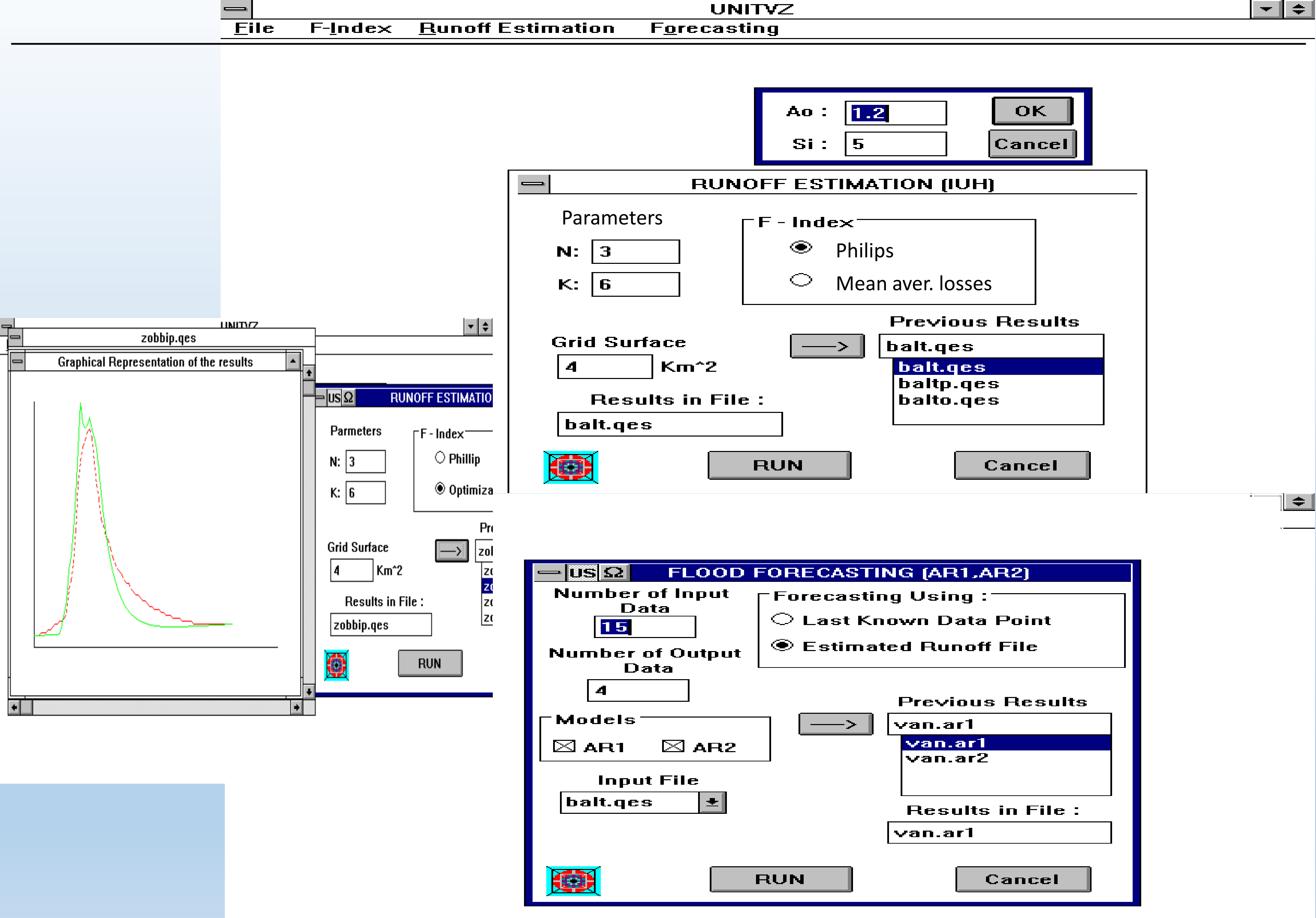

EVENT OF 25-12-93
Discharge (m^3/sec)
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
TIME (hours)
Observed
Computed by using radar
Six - hour forecast by using radar


EVENT OF 25-12-93
Discharge (m^3/sec)
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
TIME (hours)
Observed
Computed by using radar
Six - hour forecast by using one hour forecasted rainfall

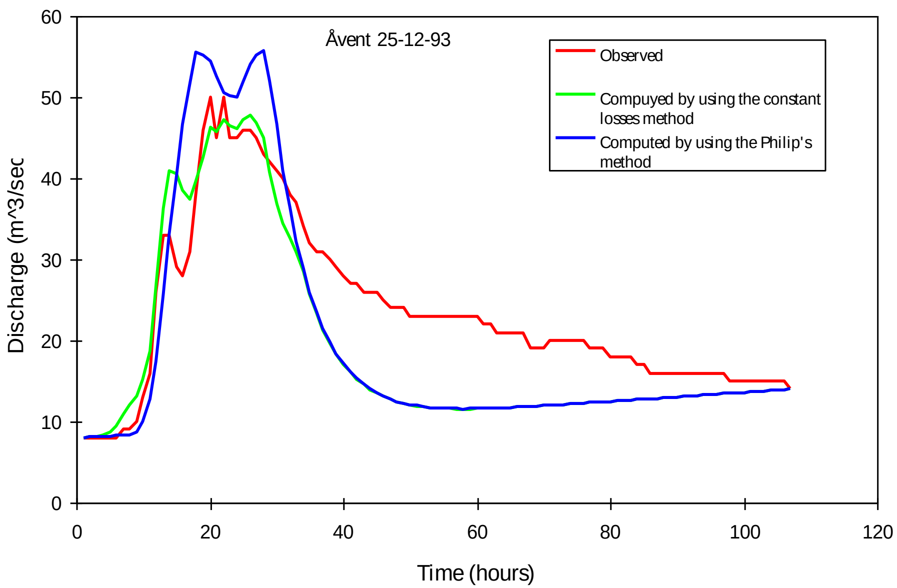

EVENT OF 25-12-93
Discharge (m^3/sec
0
10
20
30
40
50
60
70
80
0
20
40
60
TIME (hours)
Observed
Computed by using radar
Six - hour forecast by using radar

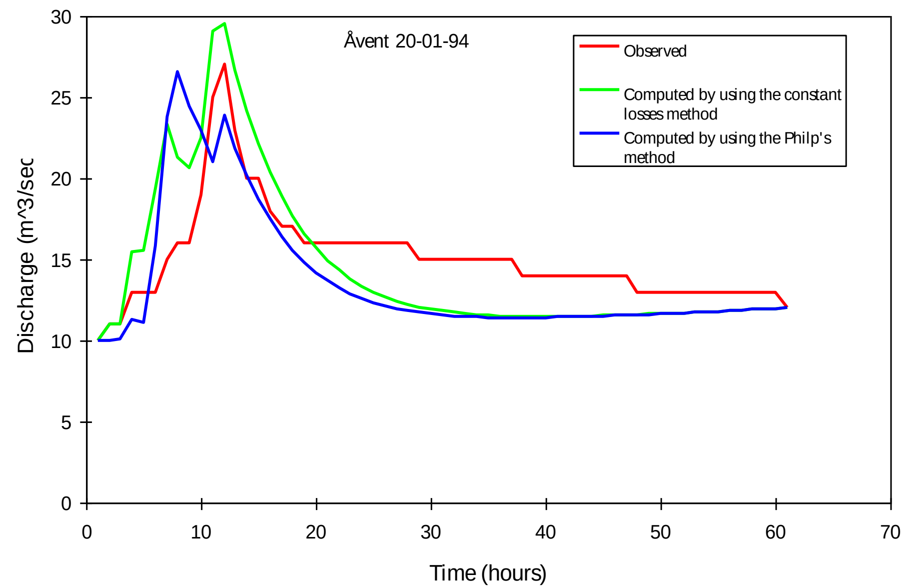

EVENT OF 25-12-93
Discharge (m^3/sec
0
10
20
30
40
50
60
70
80
90
0
20
40
60
TIME (hours)
Observed
Computed by using radar
Six - hour forecast by using two hour forecasted rainfall

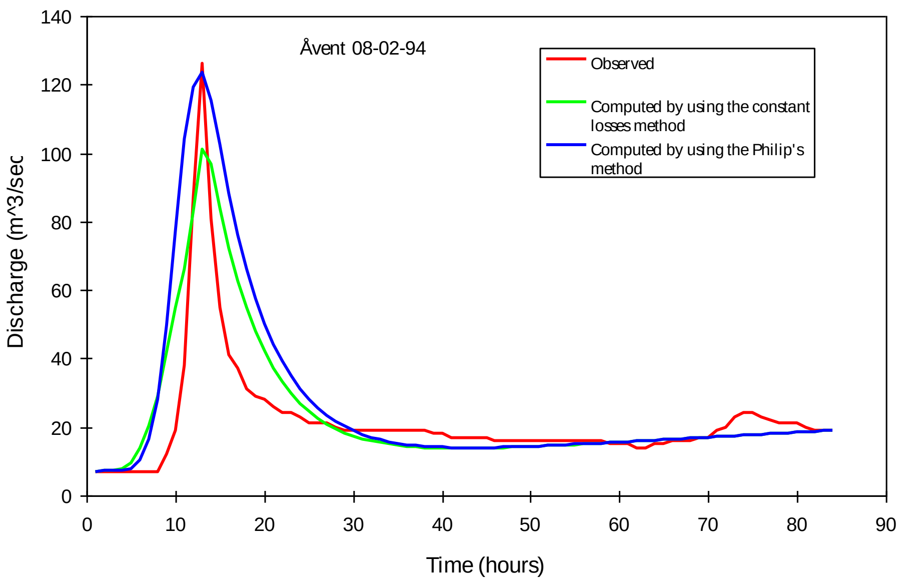

ESTIMATION *n*, K (IUH)
ANALYSIS AND PROCESSING OF HISTORICAL RAINFALL-RUNOFF EVENTS
DISTANCE OF THE CENTER OF EACH GRID FROM THE OUTLET OF THE BASIN (IN CHANNEL AND OFF CHANNEL)
ANALYSIS AND PROCESSING OF RAINGAGE, STAGE RECORDING AND RADAR DATA
CONSTANT LOSSES METHOD
DISTRIBUTED RAINFALL-RUNOFF MODEL
PHILIP METHOD
COMPARISON OF OBSERVED AND COMPUTED HYDROGRAPHS
STOCHASTIC SIMULATION AND FORECASTING OF THE ERROR TERM
GRAPHICS DISPLAY PROGRAMMES
SHORT-TERM FLASH FLOOD FORECASTING (2, 4 HOURS)

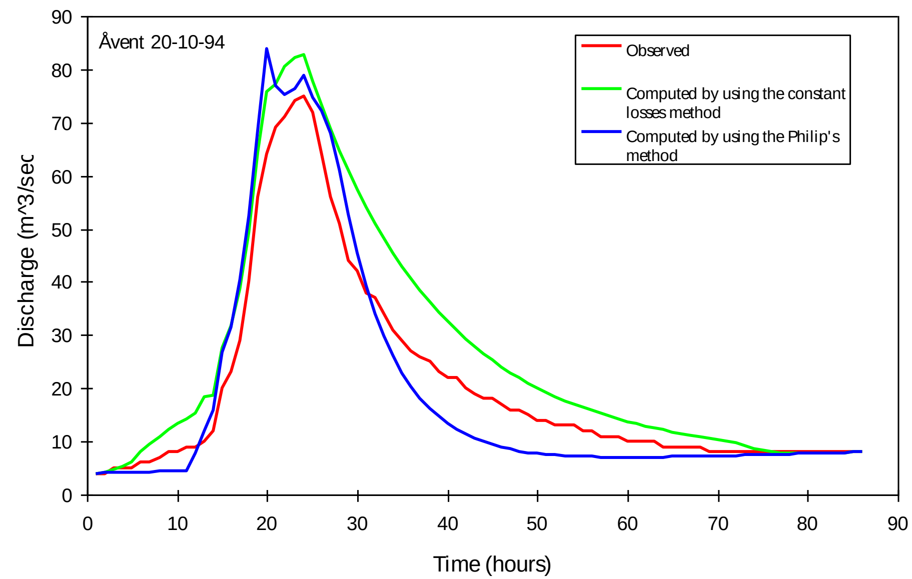


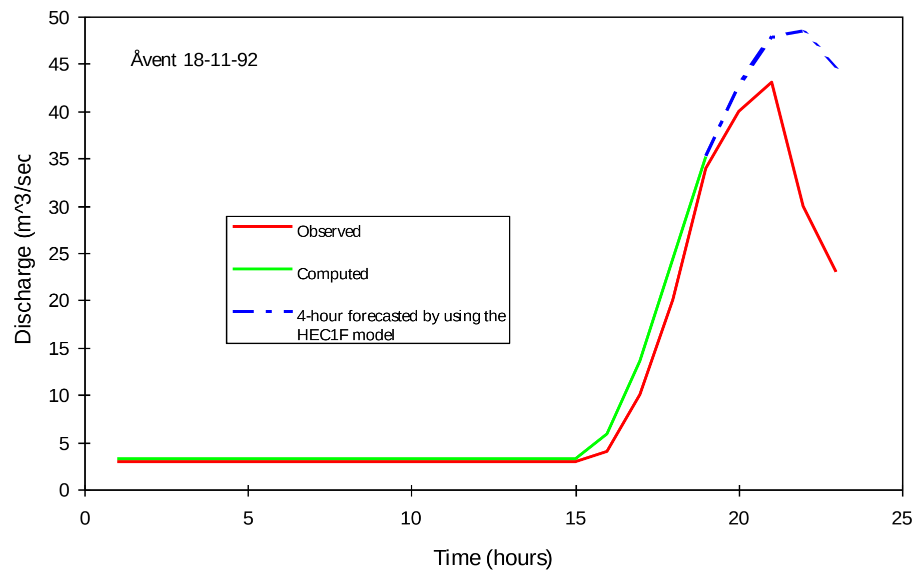
NATIONAL TECHNICAL UNIVERSITY OF ATHENS, DIVISION OF WATER RESOURCES

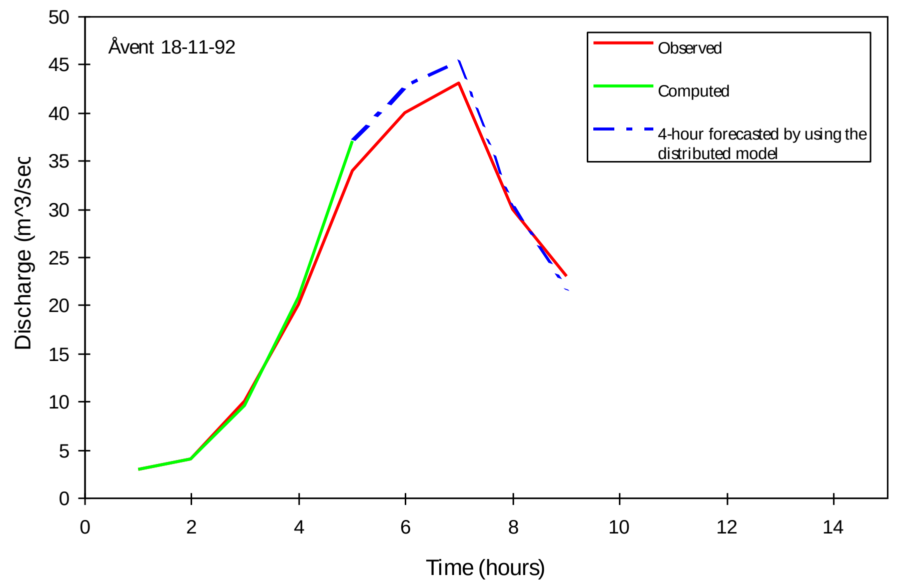

Åvent 25-12-93
Observed
Compuyed by using the constant losses method
Computed by using the Philip's method
Discharge (m^3/sec
Time (hours)


Åvent 20-01-94
Observed
Computed by using the constant losses method
Computed by using the Philp's method
Discharge (m^3/sec
Time (hours)


Åvent 08-02-94
Observed
Computed by using the constant losses method
Computed by using the Philip's method
Discharge (m^3/sec
Time (hours)


Åvent 20-10-94
Observed
Computed by using the constant losses method
Computed by using the Philip's method
Discharge (m^3/sec
Time (hours)


Åvent 18-11-92
Observed
Computed
4-hour forecasted by using the HEC1F model
Discharge (m^3/sec
Time (hours)


Åvent 18-11-92
Observed
Computed
4-hour forecasted by using the distributed model
Discharge (m^3/sec
Time (hours)

- Rainfall rate R (mm/h) :

$$R = \frac{\pi}{6} * \frac{3.6}{10^3} * \frac{1}{F * t} * \sum_{i=1}^{20} (n_i * D_i^{\ 3})$$

- Radar reflectivity factor Z (mm^6/m^3) :

$$Z = \frac{1}{F * t} * \sum_{i=1}^{20} (\frac{n_i}{V(D_i)} * D_i^{\ 6})$$

- Liquid water content W (mm^3/m^3) :

$$W = \frac{\pi}{6} * \frac{1}{F * t} * \sum_{i=1}^{20} (\frac{n_i}{V(D_i)} * D_i^{\ 3})$$

- Drop size distribution N(D):

$$N(D_i) = \frac{n_i}{F * t * V(D_i) * \Delta D_i}$$

- N_0 ($m^{-3}mm^{-1}$) :

$$N_O = \frac{1}{\pi} * (\frac{6!}{\pi})^{\frac{4}{3}} * (\frac{W}{Z})^{\frac{4}{3}} * W$$

- Ë(mm^{-1}) :

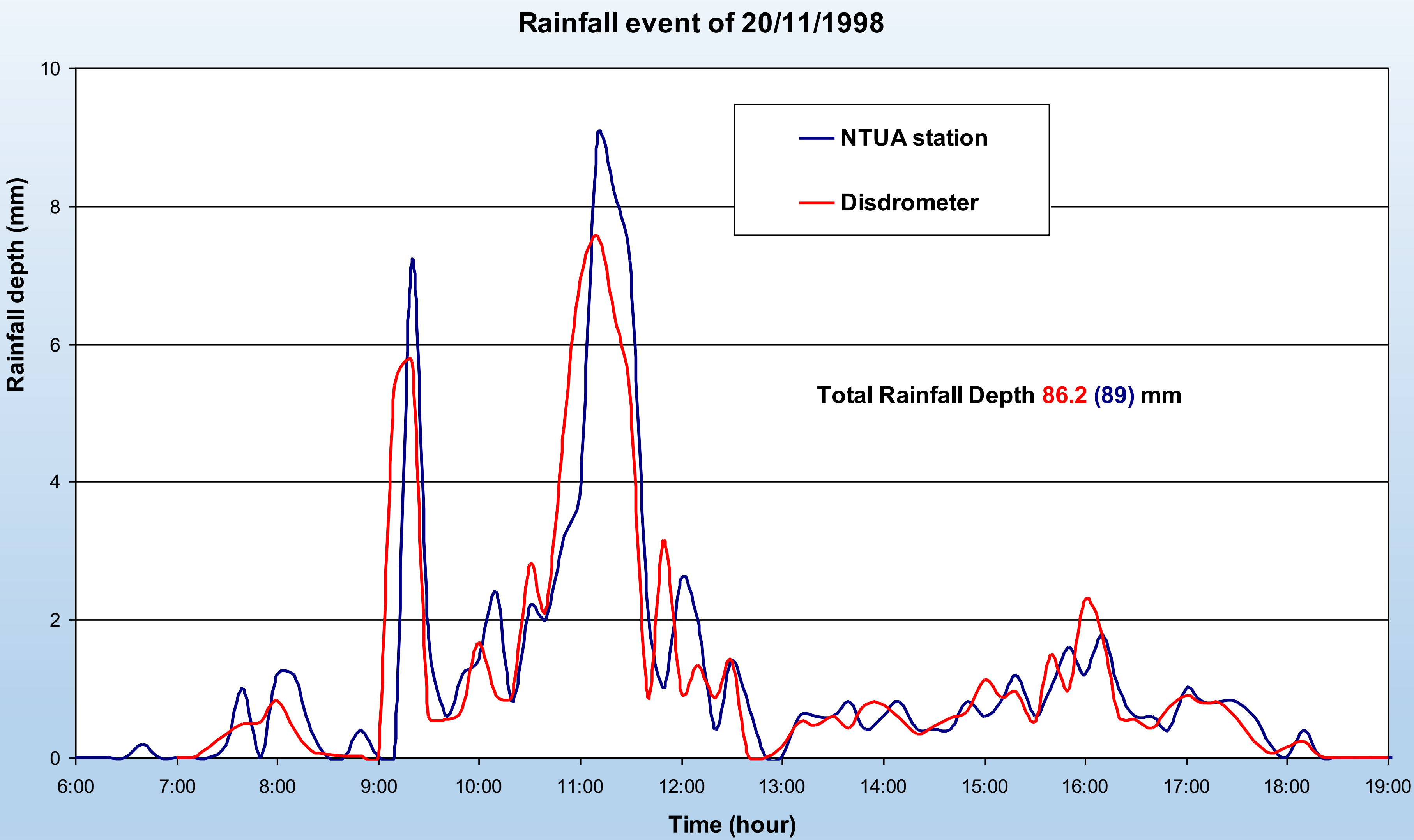
$$\Lambda = (\frac{6!}{\pi} * \frac{W}{Z})^{\frac{1}{3}}$$

- E_k (N/m^2) :

$$E_K = \frac{\pi}{12} * \frac{1}{At} \sum_{i=1}^{20} D_i^3 \, V(D_i)^2 \, N_A(D_i)$$

- Dead time correction N(i)corr. :

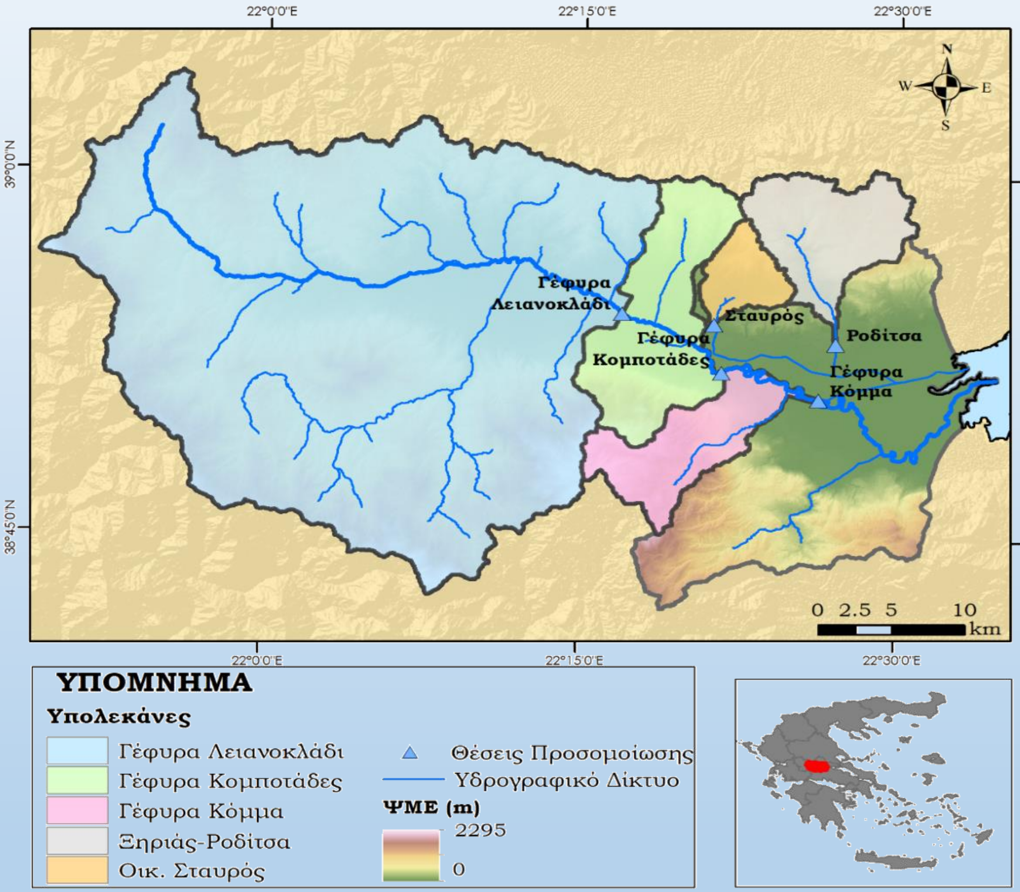
$$N_{(i)corr} = N_{(i)} * \exp(\frac{0.035}{T} * \sum_{D_k = 0.85 D_i}^{D_{k\max}} N_{(k)} * \ln \frac{D_k}{0.85(D_i - 0.25)}$$



Rainfall event of 20/11/1998
NTUA station
Disdrometer
Total Rainfall Depth 86.2 (89) mm
Rainfall depth (mm)
10
8
6
4
2
0
6:00
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
Time (hour)

Geomorphological and Hydrological Analysis

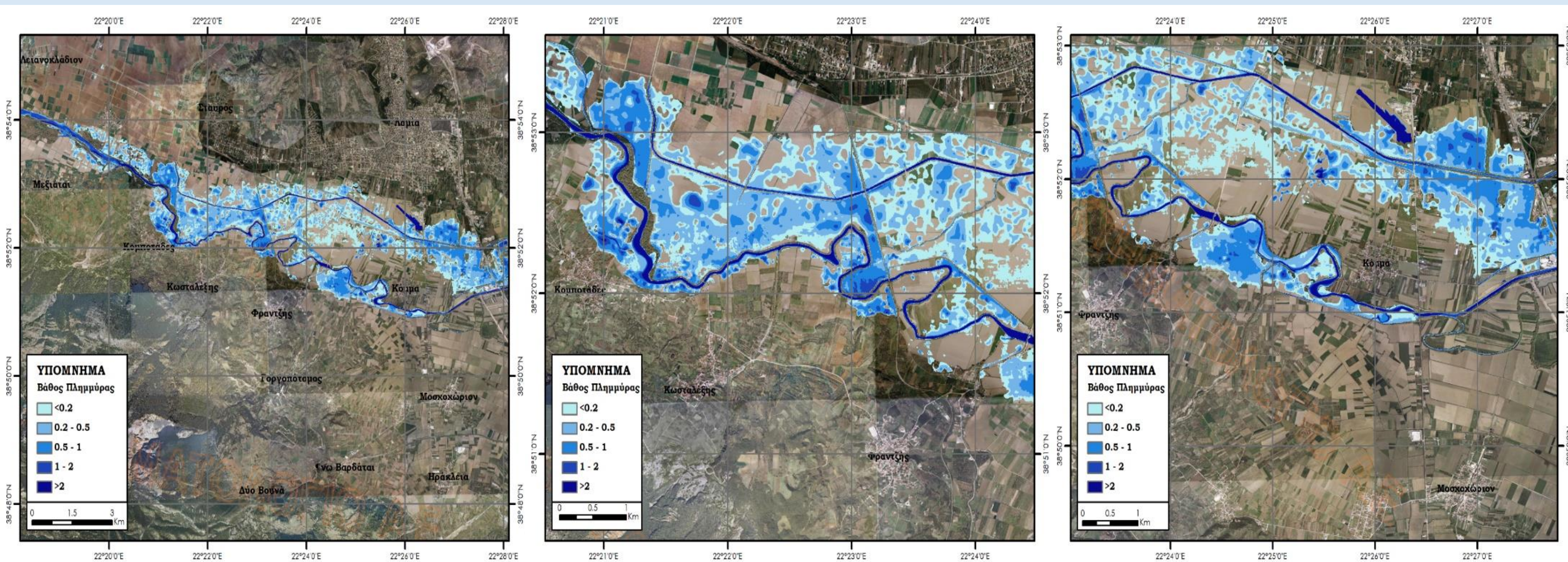
- 5 Θέσεις προσομοίωσης



Θέσεις Προσομοίωσης	Χ ΕΓΣΑ 87 (m)	Υ ΕΓΣΑ 87 (m)	Προσομοίωση
Γέφυρα Λειανοκλαδίου	364529.39	4300957.10	*Υδρολογική*
Γέφυρα Κομποτάδες	357871.75	4303093.88	*Υδρολογική*
Γέφυρα Κόμμα	351059.86	4307665.88	*Υδρολογική*
Θέση Στερεοπαροχής	357365.52	4306758.88	*Στερεοαπορροής*

Flood risk management

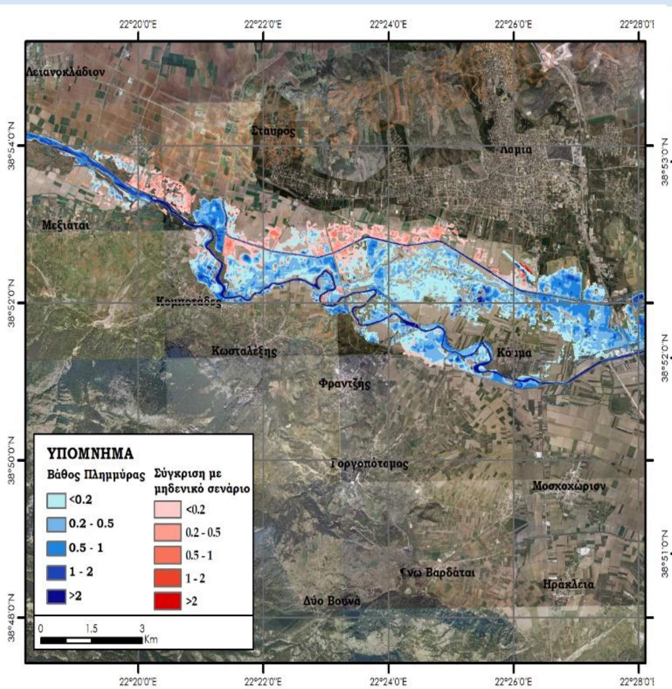
Hydraulic simulation with **Zero Scenario**



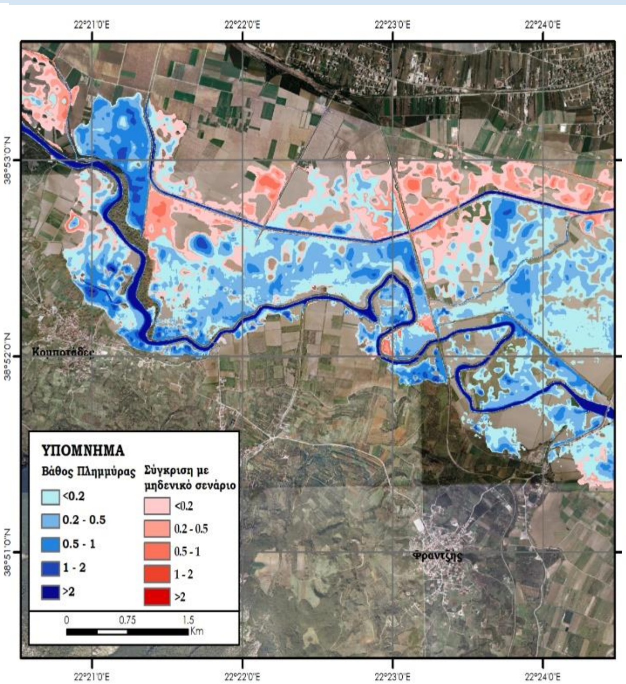
περιοχή μελέτης (συνολικά) *τμήμα Κομποτάδες – Φραντζής* *τμήμα Φραντζής – Κόμμα*

Flood risk management

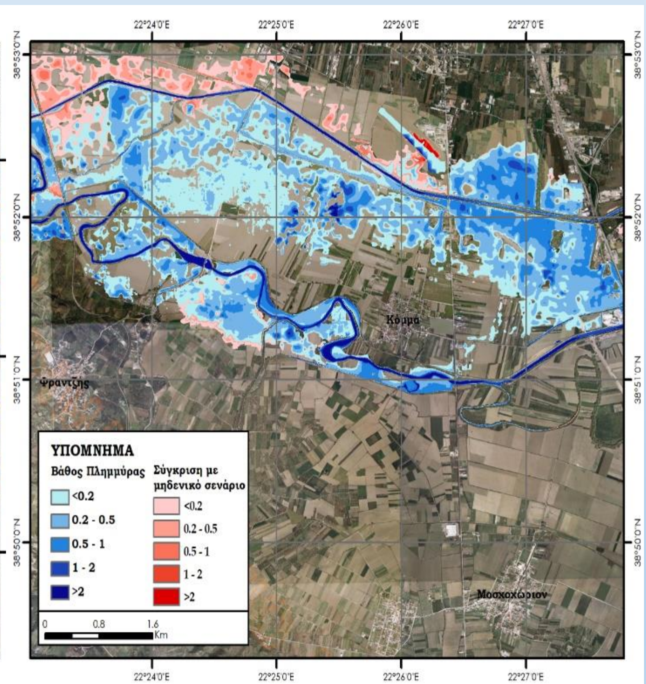
- *Scenario **1: Support of the levees***



περιοχή μελέτης (συνολικά)



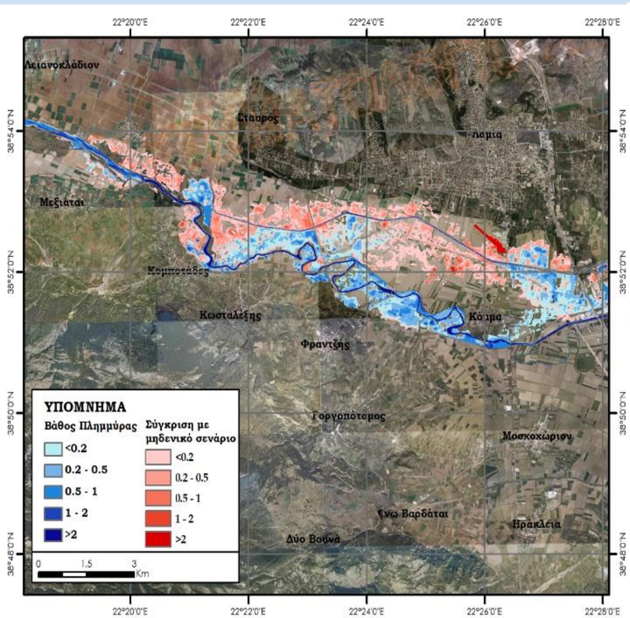
τμήμα Κομποτάδες – Φραντζής



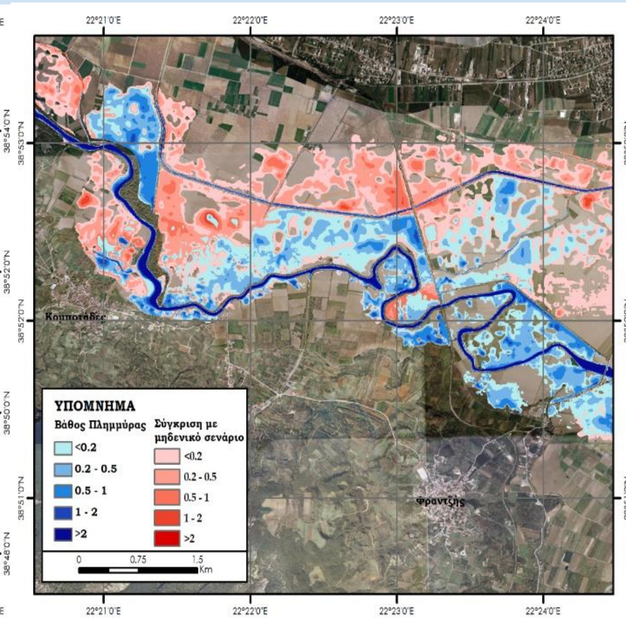
τμήμα Φραντζής – Κόμμα

Flood risk management

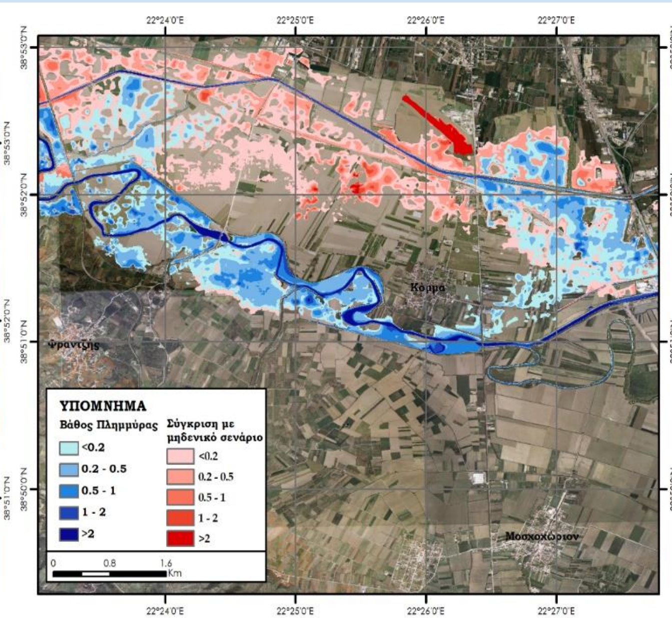
- ***Scenario 2: Support of the levees and 20% decrease of the disharge***



περιοχή μελέτης (συνολικά)

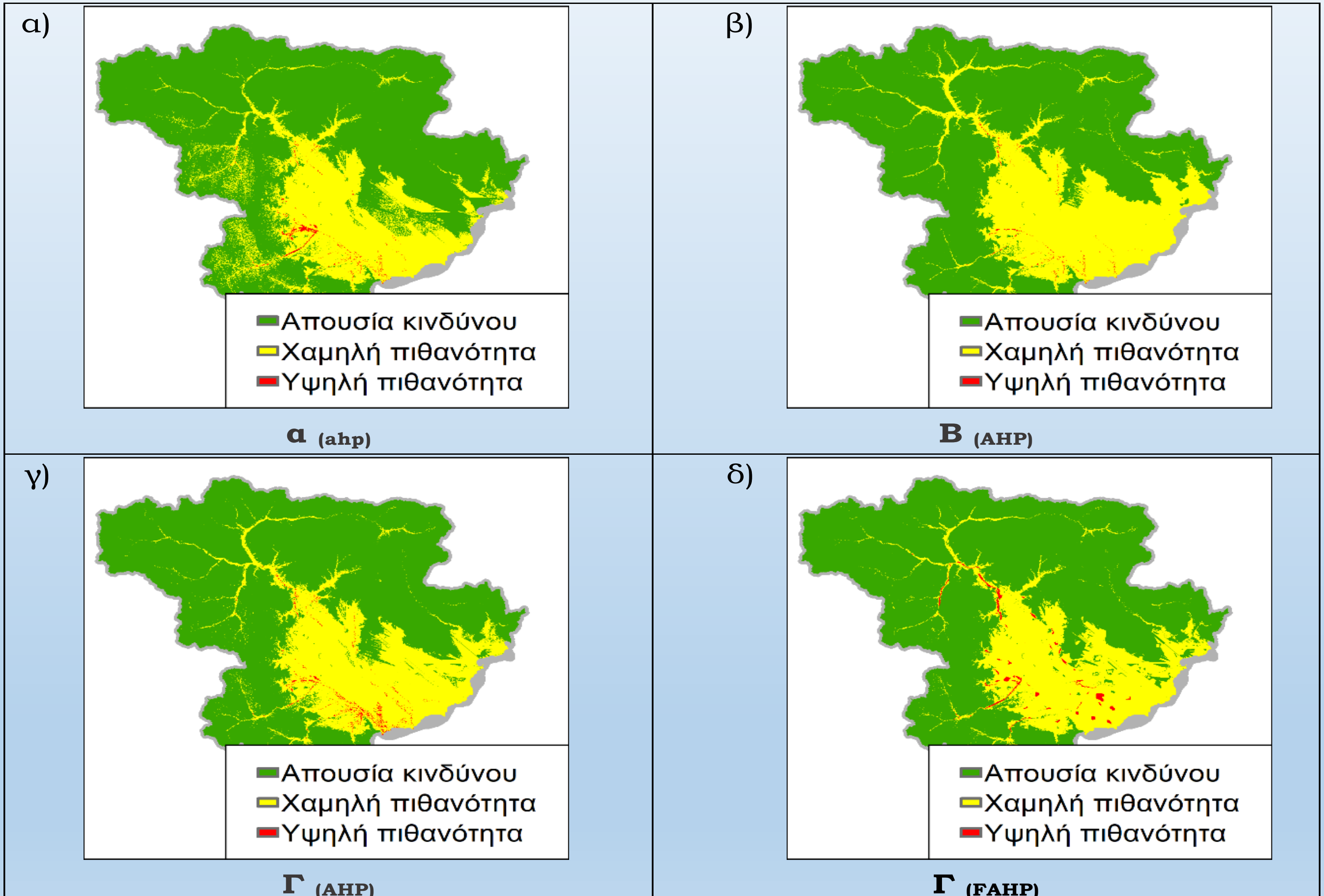


τμήμα Κομποτάδες – Φραντζής



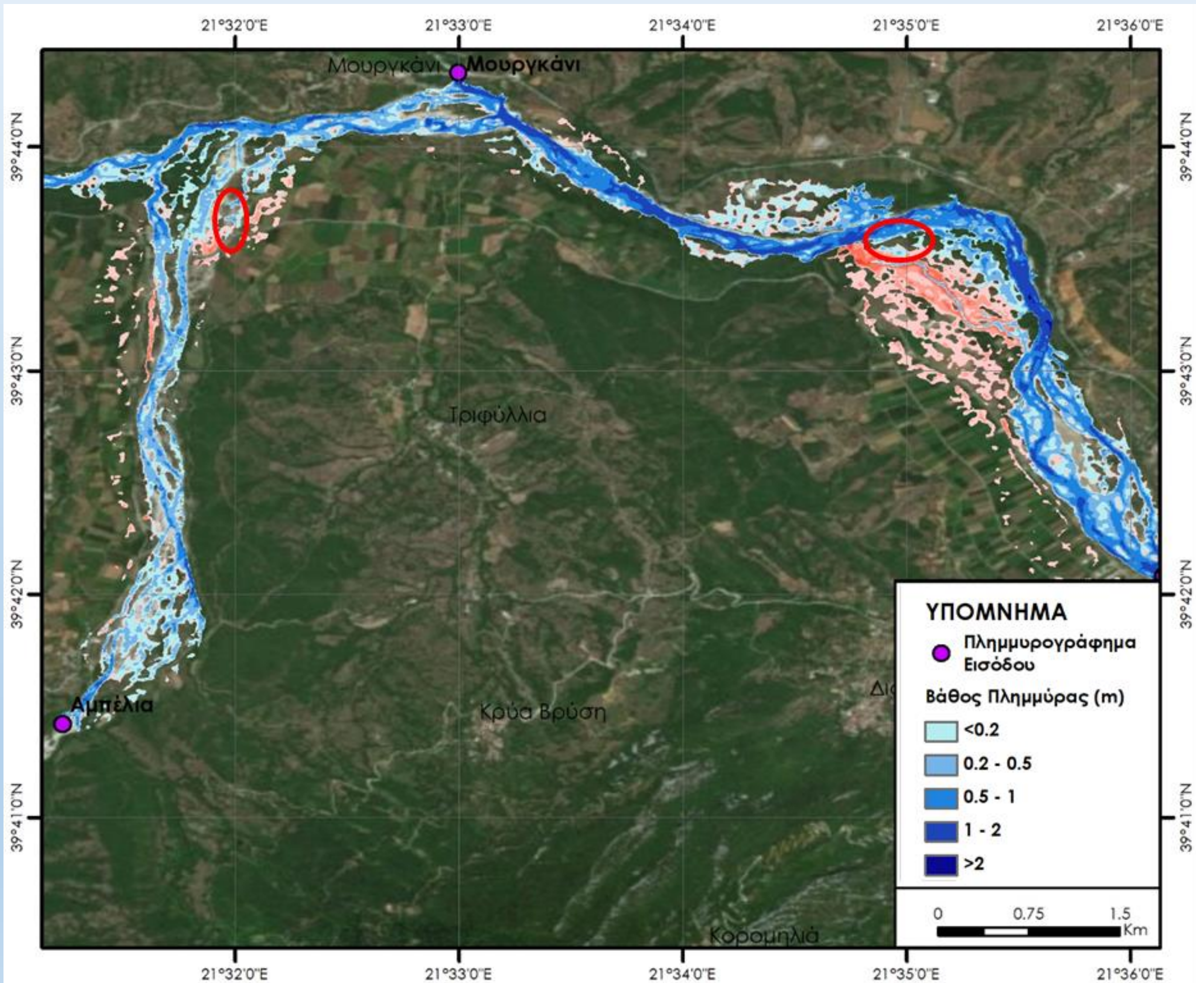
τμήμα Φραντζής – Κόμμα

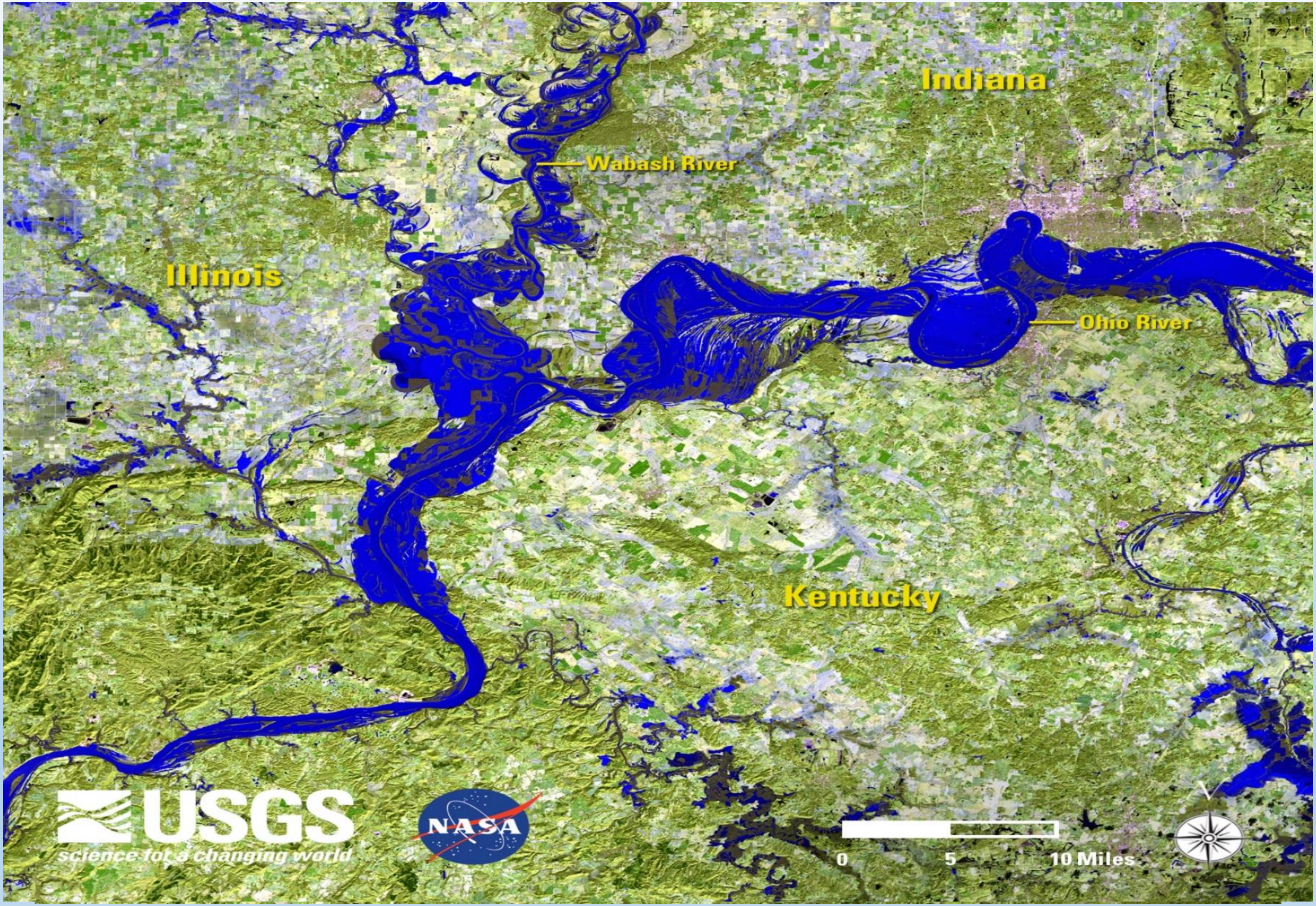
Sensitive flood areas



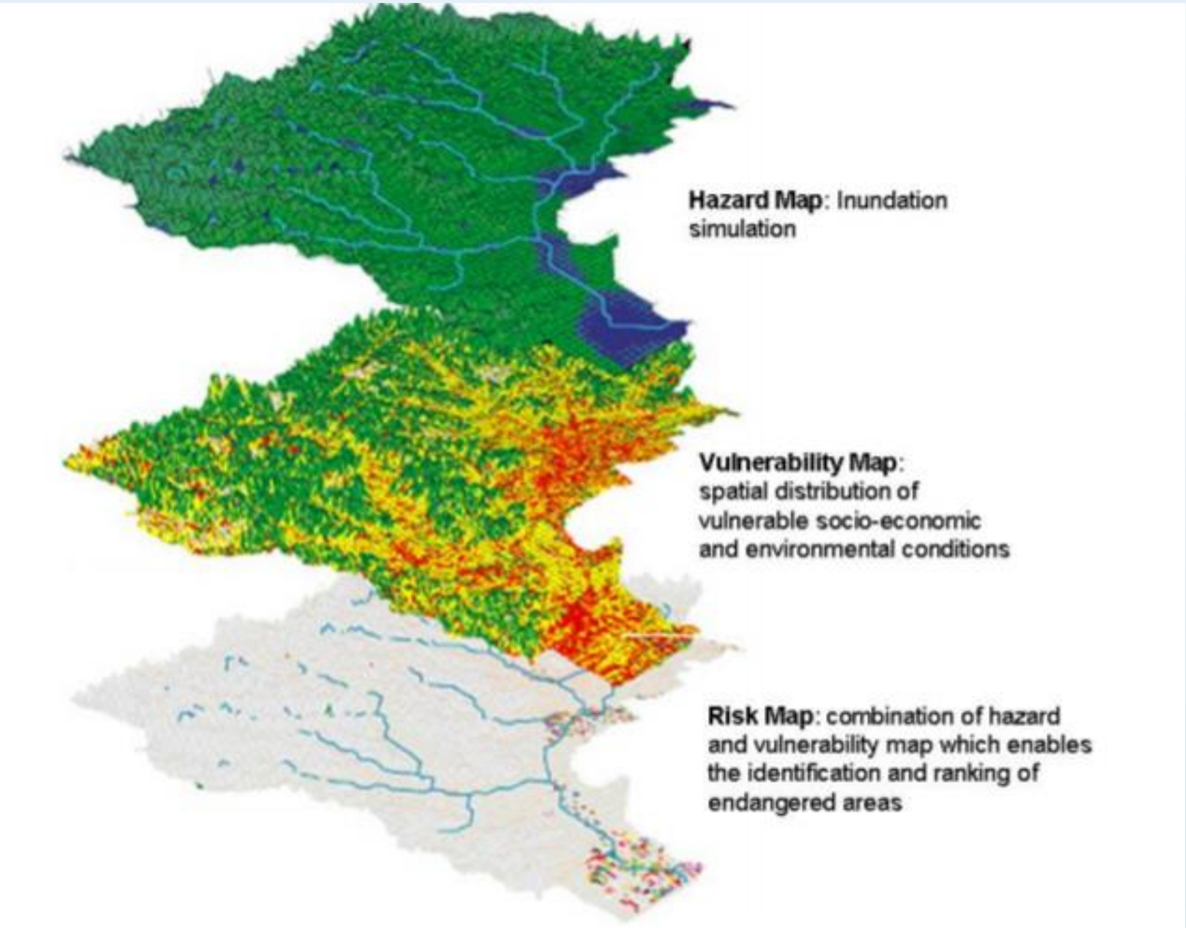
Sensitive flood locations

Flood Hazard Map




Indiana
Wabash River
Illinois
Ohio River
Kentucky
USGS
science for a changing world
NASA
0
5
10 Miles

Flood risk management and new technologies

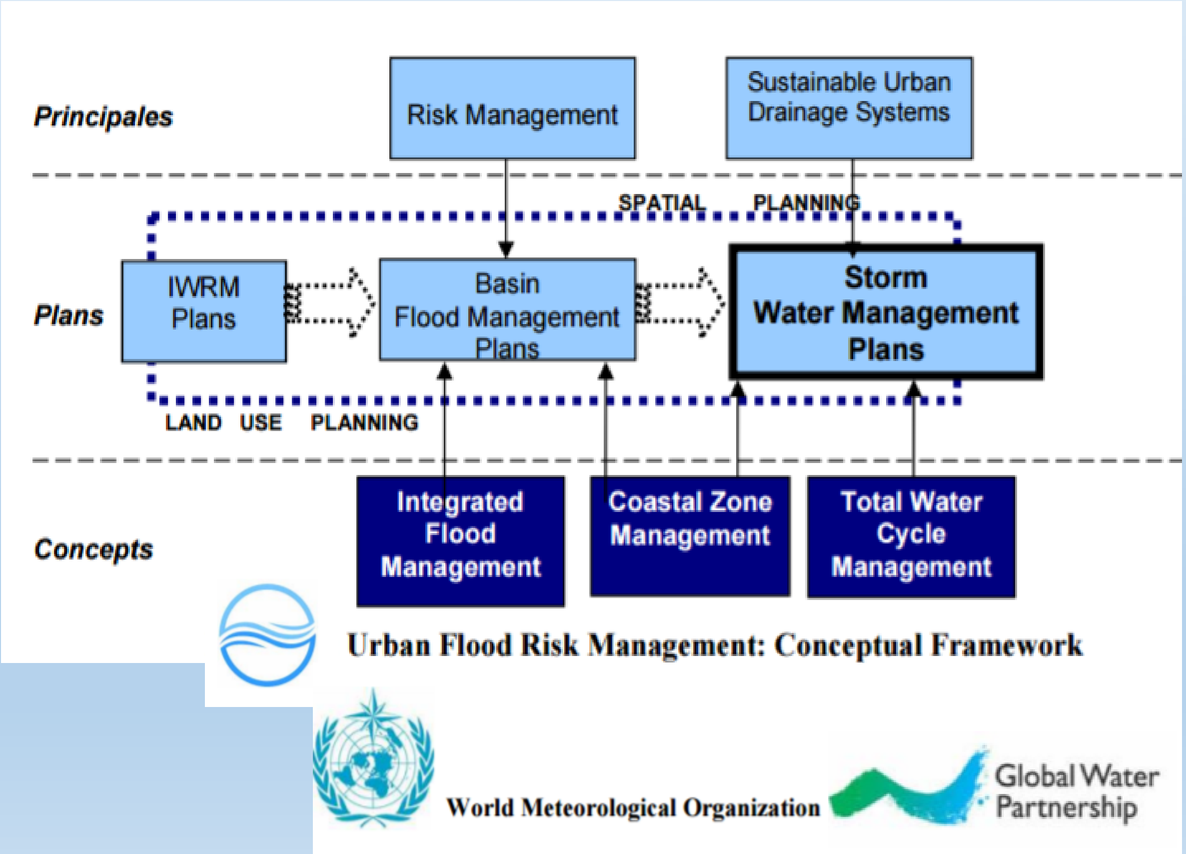


http://www.adrc.or.jp/publications/Venten/HP/herath4.jpg

Conceptual framework of flood risk management

Information Technology 'IT'

- Integrated WRM
- Land use planning

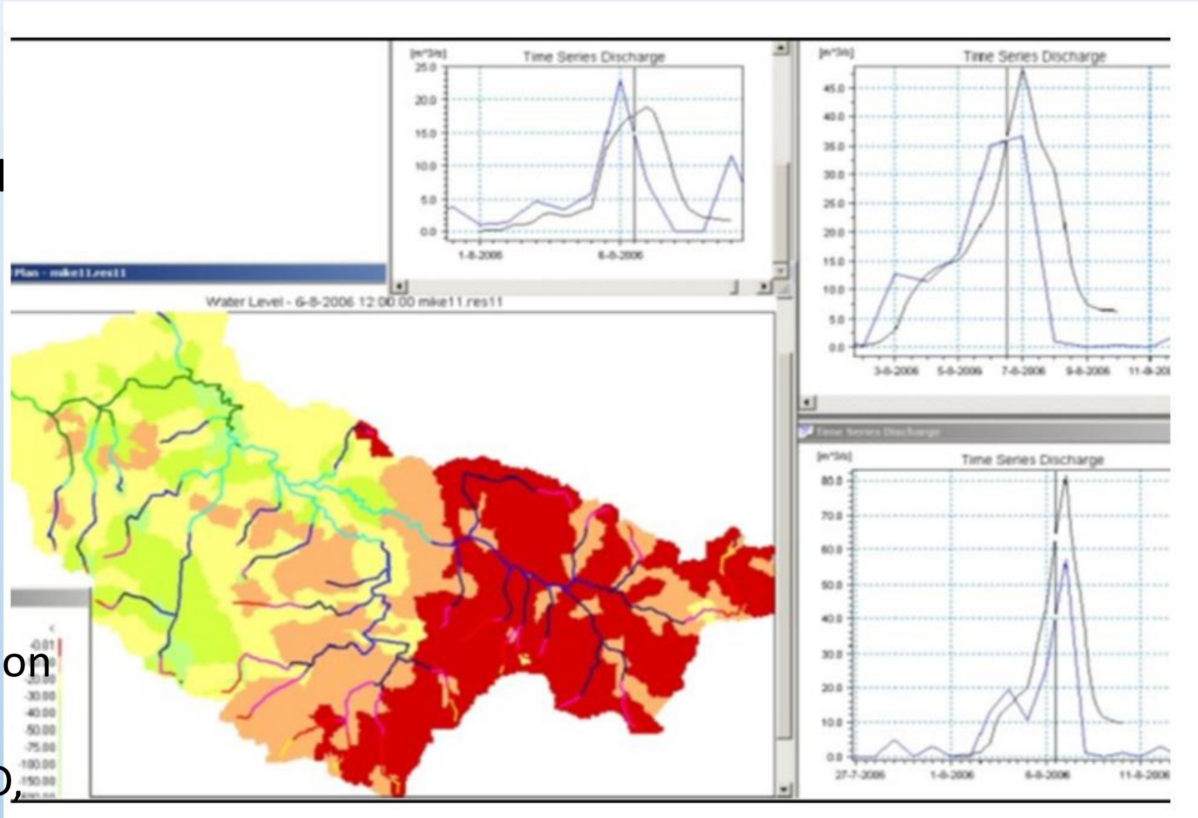


Conceptual framework of flood risk management – Early Warning System

Caution → Warning → Alert

Data input:

- Meteorological prediction
- Disdrometer, Weather Radars, Automated meteorological and hydrological stations



Source: DHI Group

Παράδειγμα προσομοιωμένου κινδύνου πλημμύρας σε χάρτη για μια περιοχή 4000 km² (ποταμός Sázava, Τσεχία).

Στα διαγράμματα συγκρίνονται οι προσομοιωμένες τιμές παροχών (μαύρο) με τις μετρημένες (μπλε) σε τρεις θέσεις.

Methodology:

- Hydrologic – Hydraulic simulation rainfall - runoff (Hydrographs)
- Hydrodynamic simulation 1-2 D, Routing.
- Visualization of the results and decision making

EWS

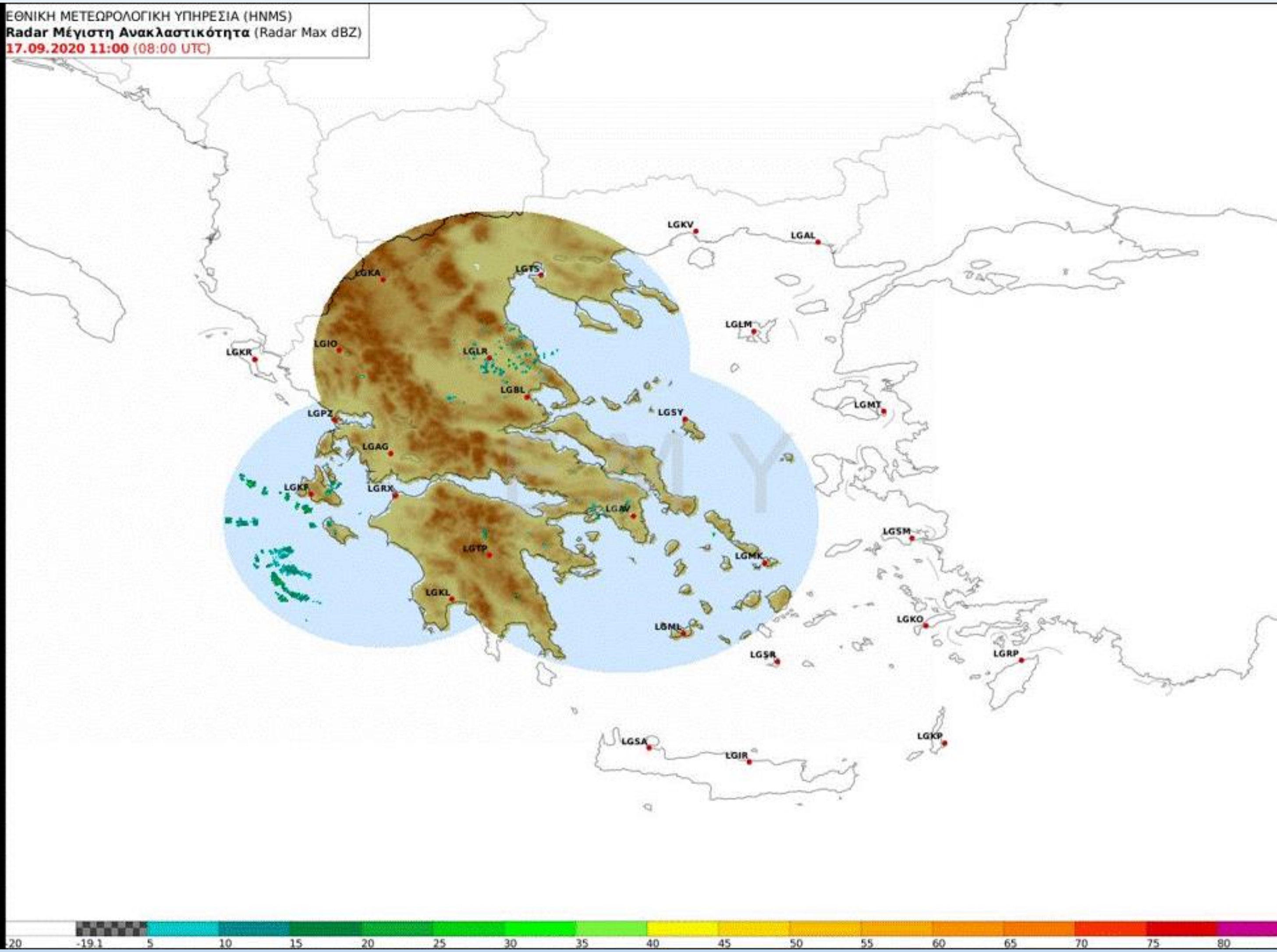
Real time operation

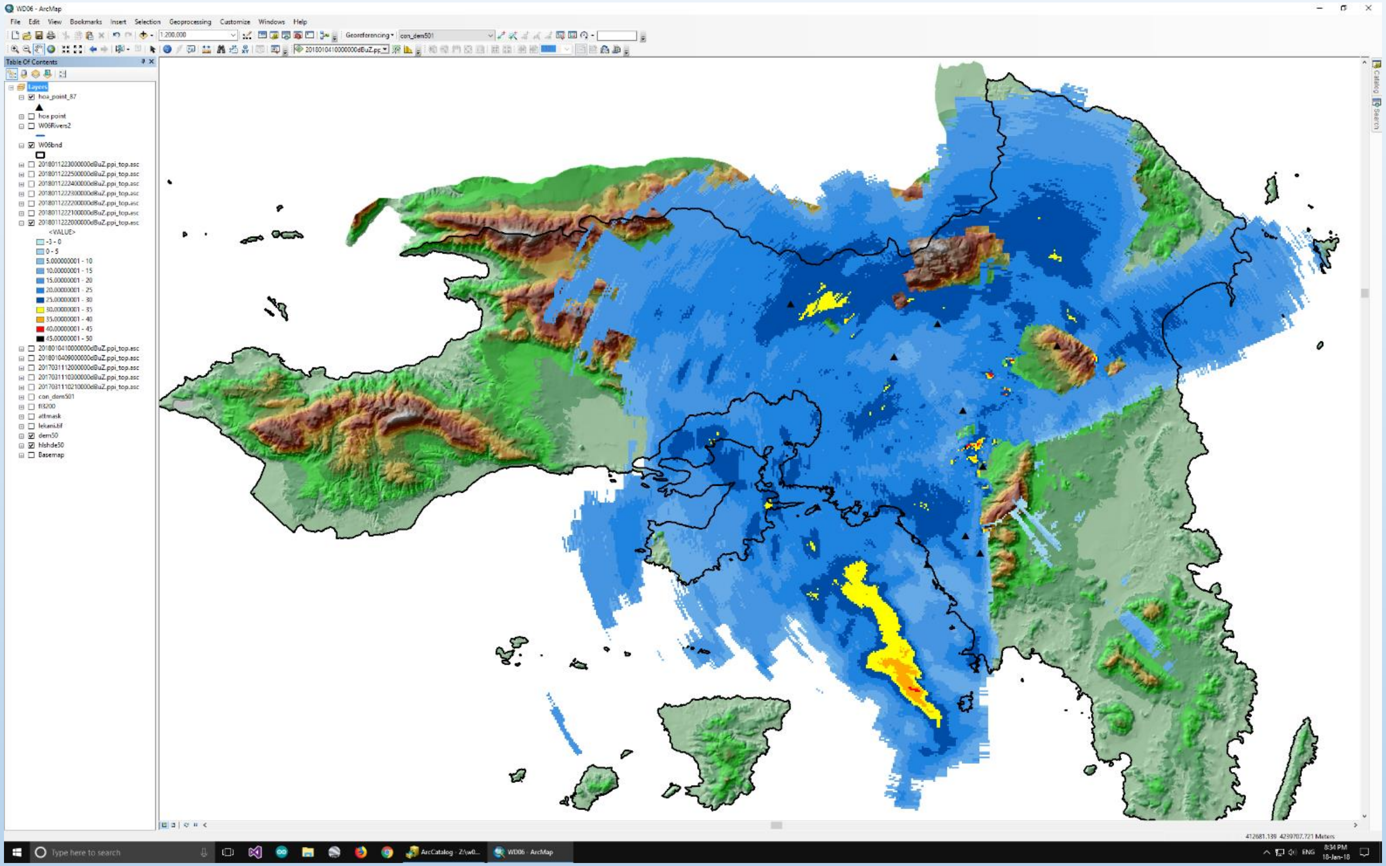
Rainfall → Recognition of flood hazards → Response

System Indication		*Response*
RED WARNING		EVACUATION
ORANGE WARNING		ALERT
YELLOW WARNING		MONITOR

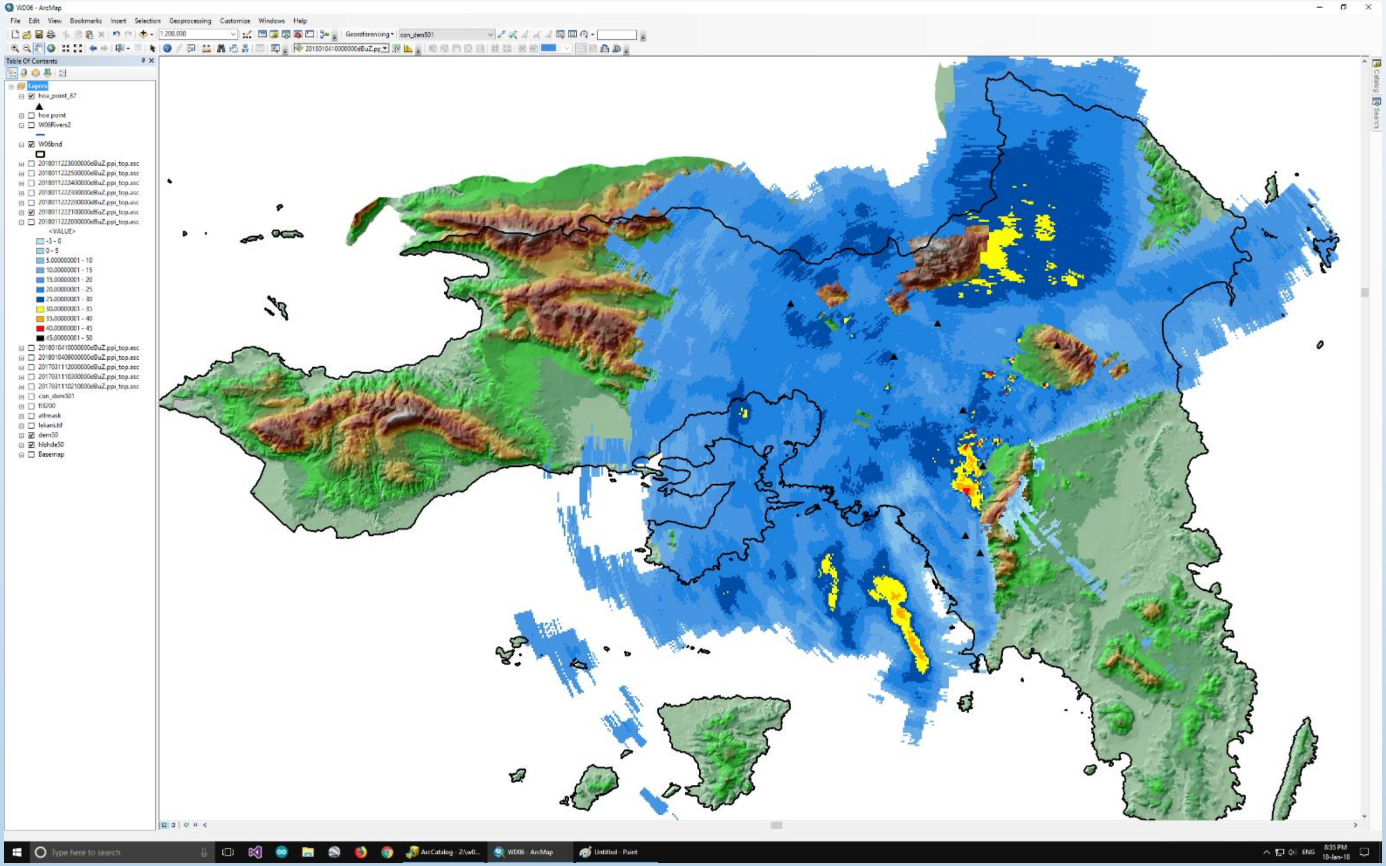
GREEN

Flood event September 2020

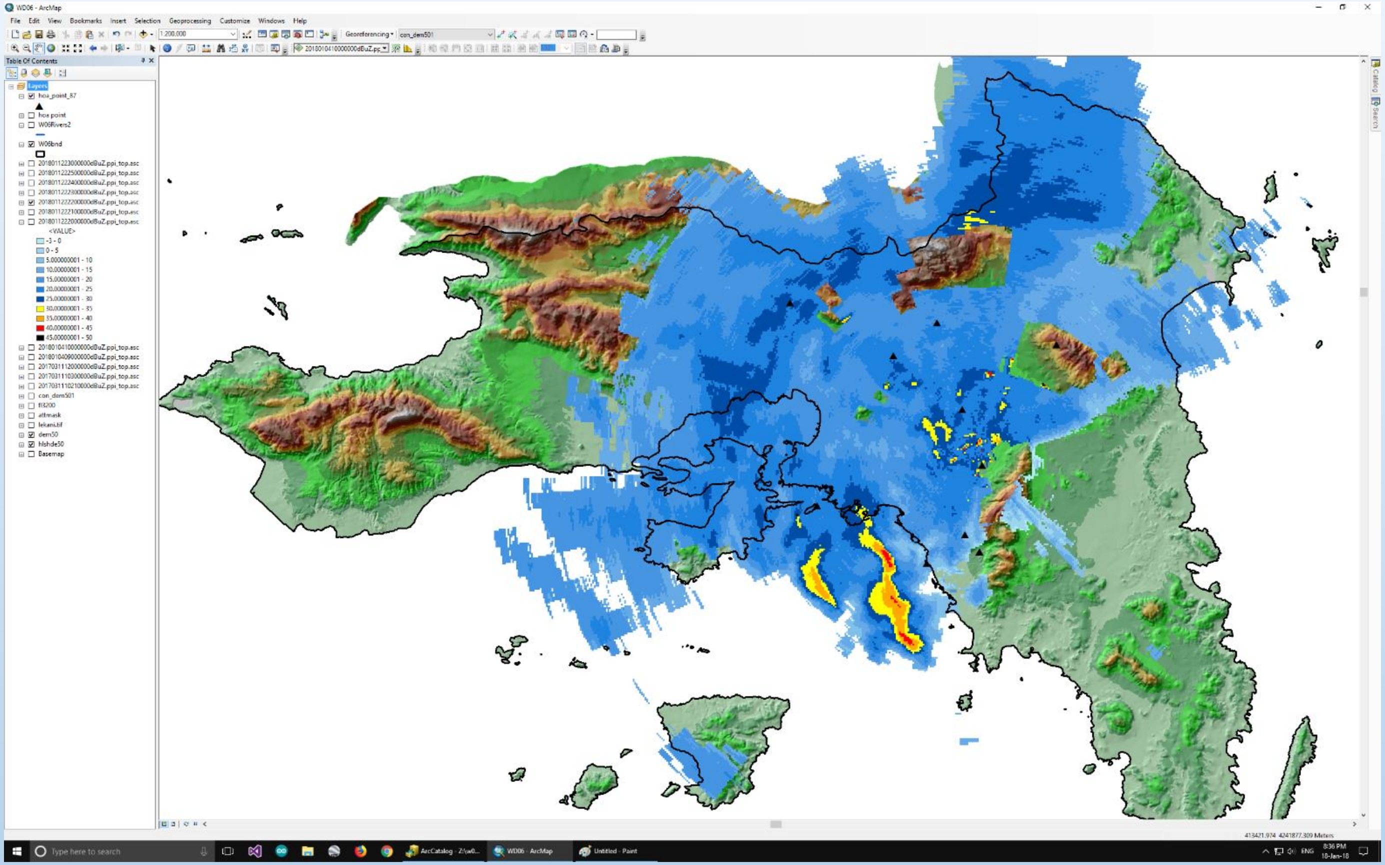




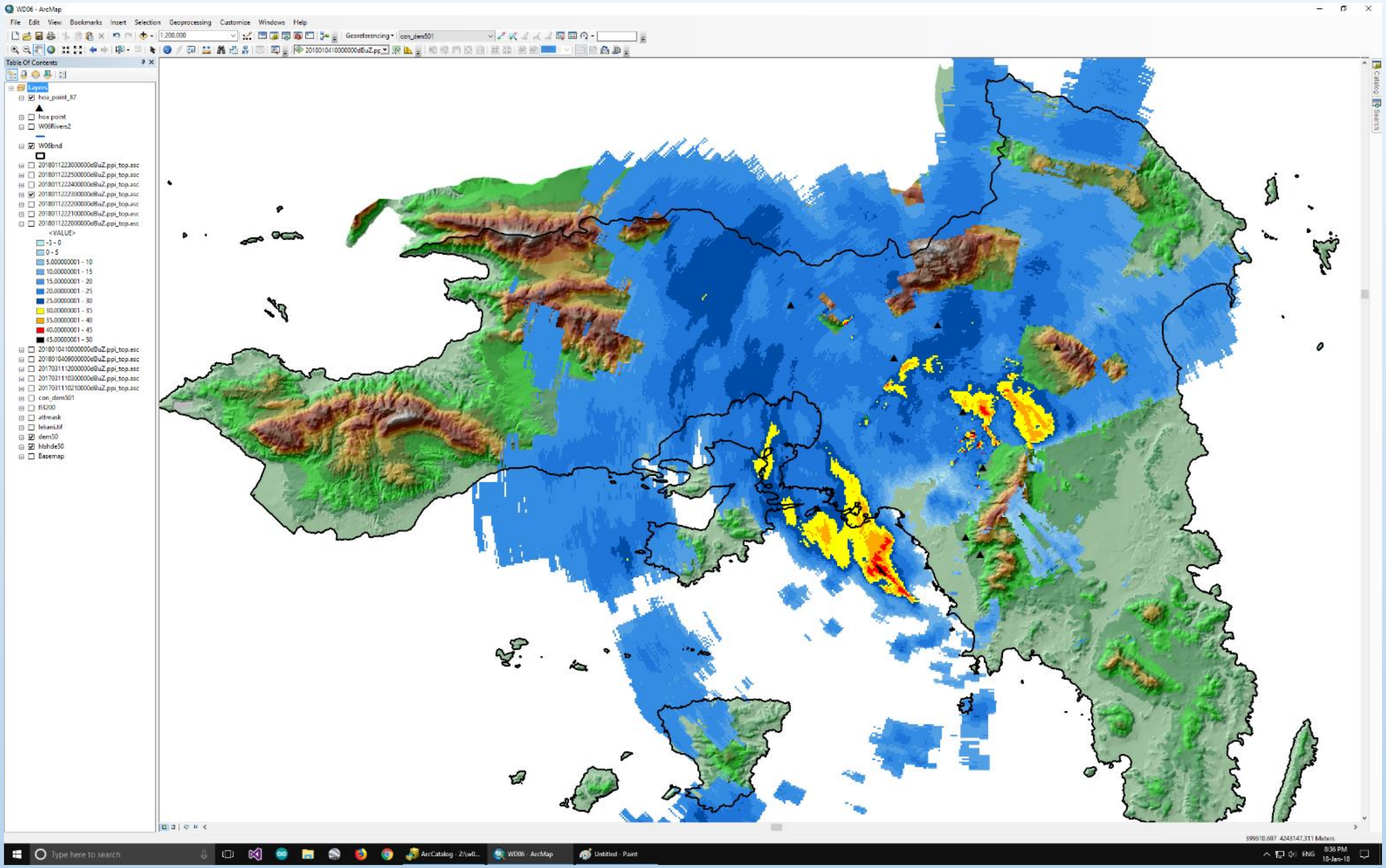
Rainfall Event 13-01-2018 (00:00)



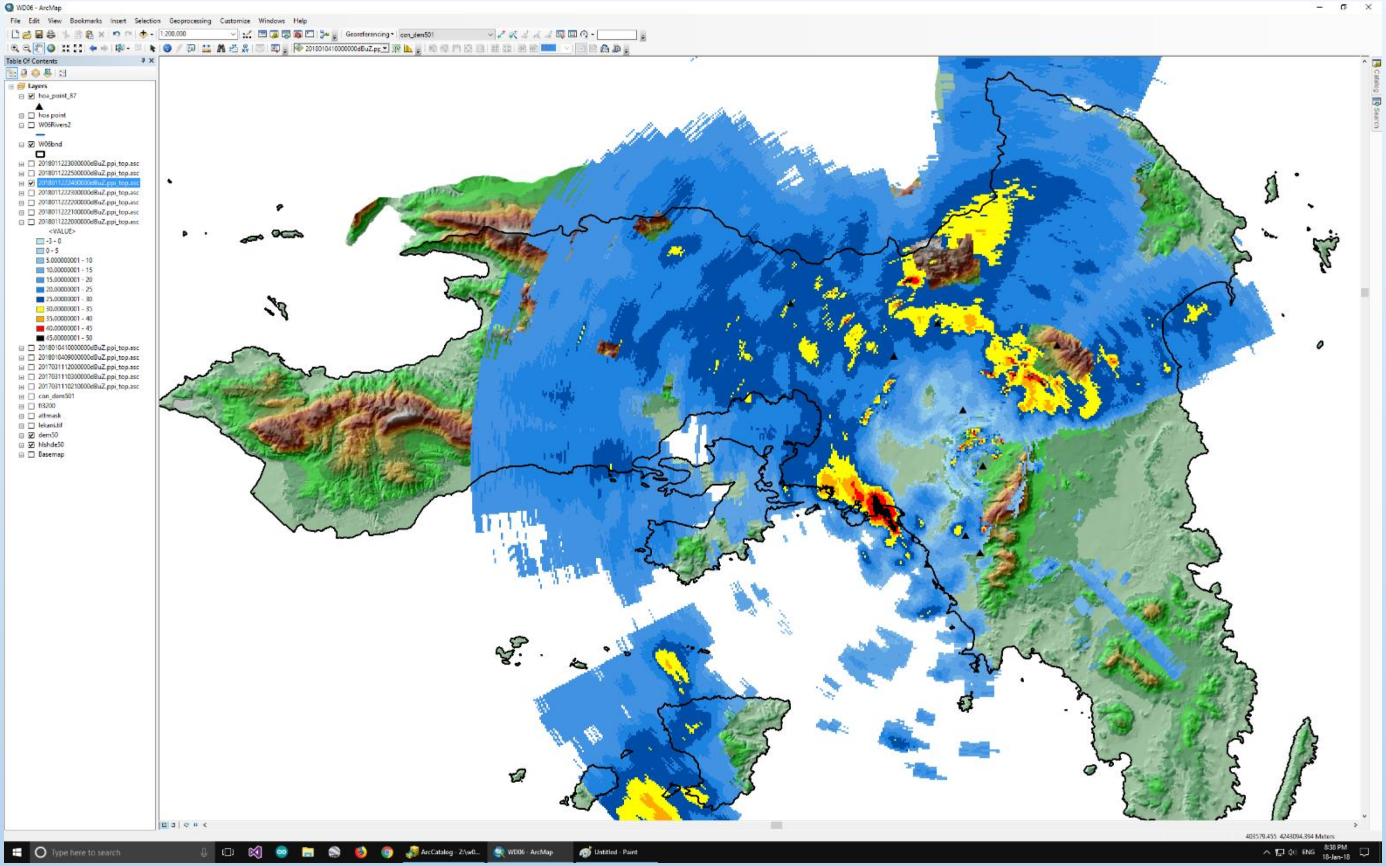
Rainfall Event 13-01-2018 (00:10)



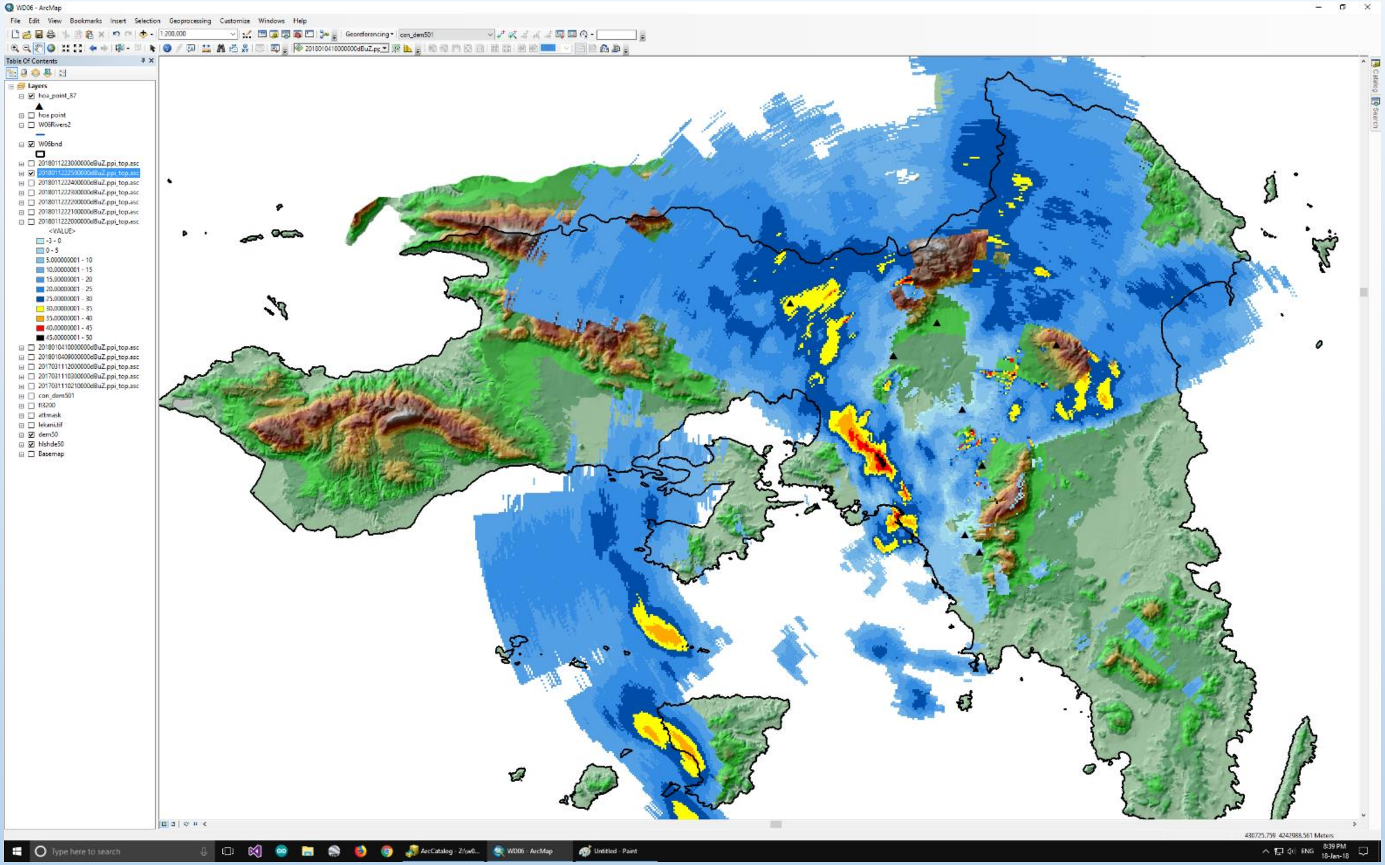
Rainfall Event 13-01-2018 (00:20)



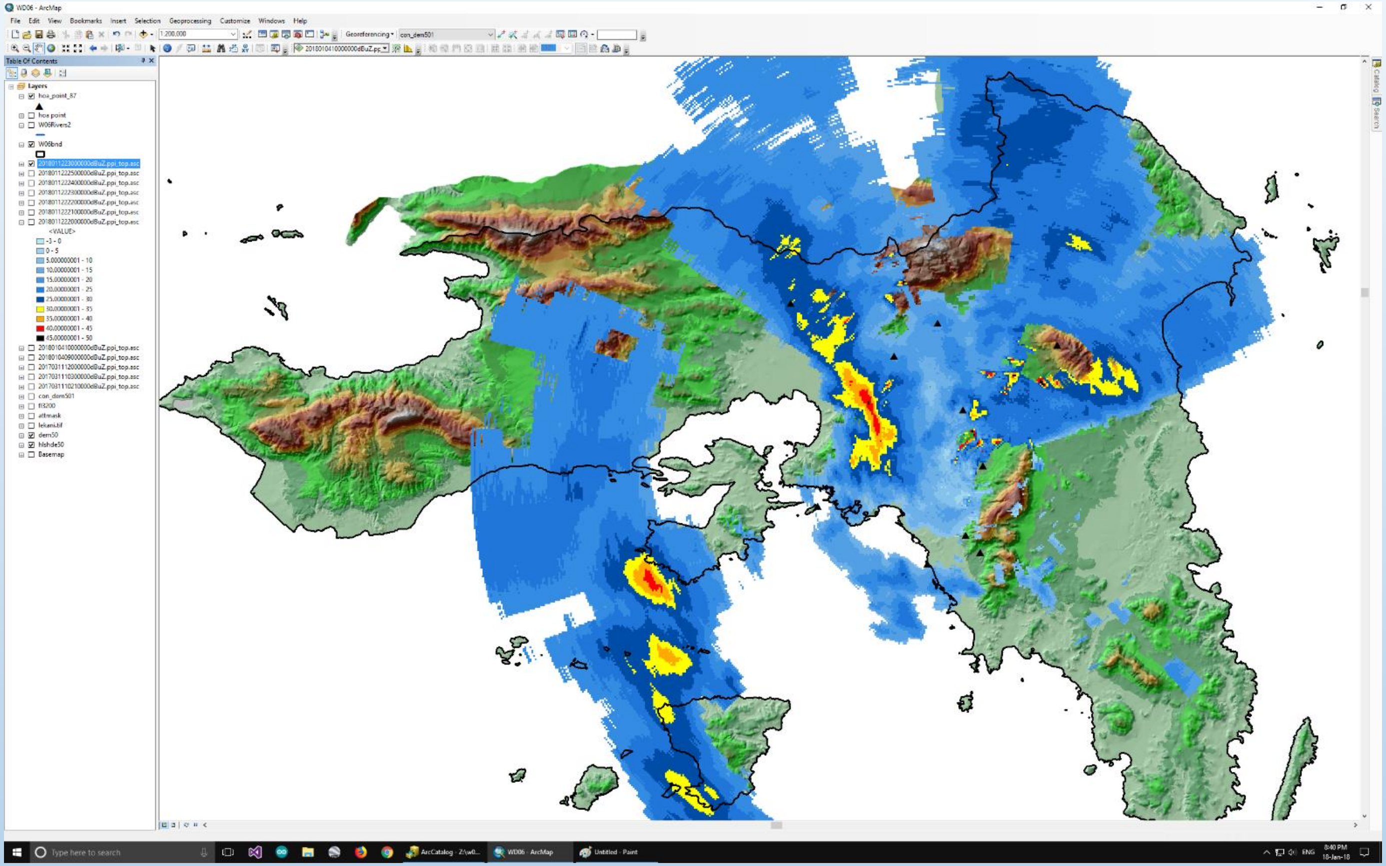
Rainfall Event 13-01-2018 (00:30)



Rainfall Event 13-01-2018 (00:40)



Rainfall Event 13-01-2018 (00:50)



Rainfall Event 13-01-2018 (01:00)

CONCLUSIONS

- A NUMBER OF STORM EVENTS CREATING FLASH FLOODS WERE ANALYSED AND PROCESSED - THE RADAR RAINFALL MEASUREMENTS WERE SLIGHTLY OVERESTIMATED COMPARING TO THE RAINGAGE ONES
- DEVELOPMENT AND APPLICATION OF METHODS FOR SHORT-TERM RADAR RAINFALL FORECASTING
- THE RAINFALL-RUNOFF MODEL WAS APPLIED IN A LUMPED AND IN A SEMI-DISTRIBUTED MANNER USING RAINGAGE AND RADAR DATA AS WELL WITH SATISFACTORY RESULTS AND SLIGHTLY BETTER USING RADAR DATA
- DEVELOPMENT AND APPLICATION OF THE GRID BASED MODEL IN THE PYLI BASIN AND COMPARISON WITH OTHER MODELS
- INSTALLATION AND OPERATION OF THE JOSS-TYPE DISTROMETER AND COMPARISON WITH THE RESULTS OF THE NTUA STATION
- FURTHER INVOLVEMENT OF GIS TECHNIQUES IN THE GRID BASED MODEL FOR DEDUCING SLOPES, LAND-USE, TYPE SOIL etc.